PB84-168756

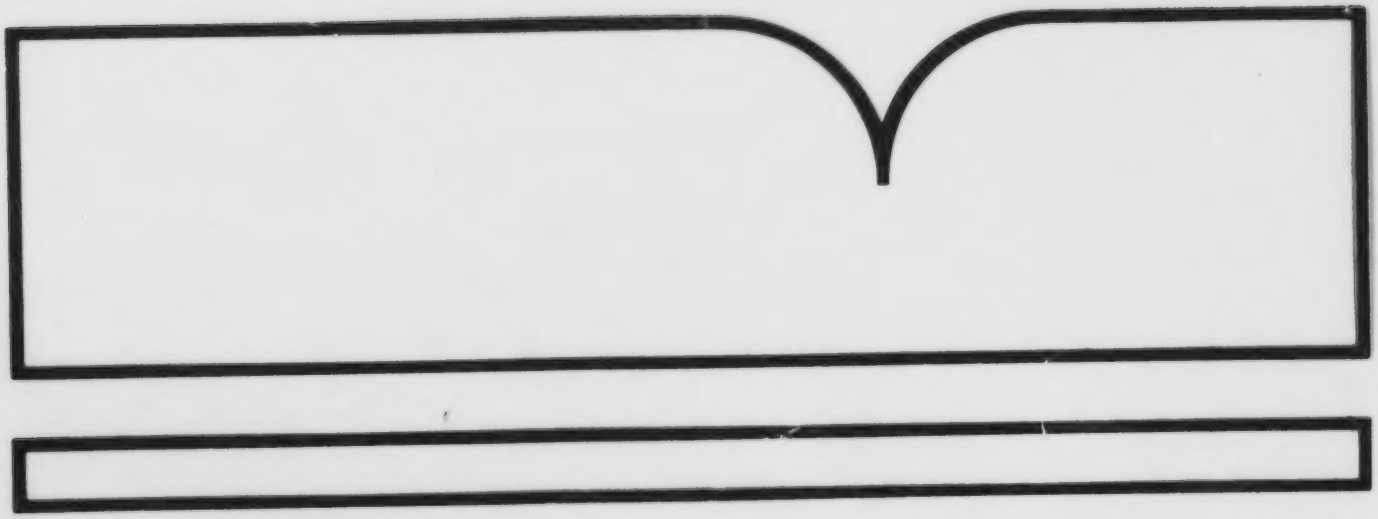
Effects of Sewage Sludge on Corn Silage and Animal Products

Department of Agriculture, Washington, DC

Prepared for

Municipal Environmental Research Lab.
Cincinnati, OH

Mar 84



U.S. Department of Commerce
National Technical Information Service
NTIS

PB84-168756

EPA-600/2-84-075
March 1984

EFFECTS OF SEWAGE SLUDGE ON CORN SILAGE AND ANIMAL PRODUCTS

by

R. H. Dowdy
U.S. Department of Agriculture
University of Minnesota
St. Paul, Minnesota 55108

and

R. D. Goodrich, W. E. Larson,
B. J. Bray and D. E. Pamp
University of Minnesota
St. Paul, Minnesota 55108

Interagency Agreement EPA-80-D-X0428

Project Officer

G. Kenneth Dotson
Wastewater Research Division
Municipal Environmental Research Laboratory
U.S. Environmental Protection Agency
Cincinnati, Ohio 45268

This study was conducted in cooperation with
U.S. Department of Agriculture

MUNICIPAL ENVIRONMENTAL RESEARCH LABORATORY
OFFICE OF RESEARCH AND DEVELOPMENT
U.S. ENVIRONMENTAL PROTECTION AGENCY
CINCINNATI, OHIO 45268

REPRODUCED BY
NATIONAL TECHNICAL
INFORMATION SERVICE
U.S. DEPARTMENT OF COMMERCE
SPRINGFIELD, VA. 22161

TECHNICAL REPORT DATA
(Please read Instructions on the reverse before completing)

1. REPORT NO.	2.	3. RECIPIENT'S ACCESSION NO.
EPA-600/2-84-075		PB84 168756

4. TITLE AND SUBTITLE	5. REPORT DATE
Effects of Sewage Sludge on Corn Silage and Animal Products	March 1984
	6. PERFORMING ORGANIZATION CODE
7. AUTHOR(S) R. H. Dowdy, R. D. Goodrich, W. E. Larson, B. J. Bray, and D. E. Pamp	8. PERFORMING ORGANIZATION REPORT NO.
9. PERFORMING ORGANIZATION NAME AND ADDRESS U. S. Department of Agriculture and University of Minnesota, St. Paul, MN 55108	10. PROGRAM ELEMENT NO. CAZB1B 11. CONTRACT/GRANT NO. IAG EPA-80-D-X0428
12. SPONSORING AGENCY NAME AND ADDRESS Municipal Environmental Research Laboratory - Cin.,OH Office of Research and Development U. S. Environmental Protection Agency Cincinnati, Ohio 45268	13. TYPE OF REPORT AND PERIOD COVERED Final 6/76-9/81 14. SPONSORING AGENCY CODE EPA/600/14

15. SUPPLEMENTARY NOTES

Project Officer: G. Kenneth Dotson (513) 684-7661

16. ABSTRACT

Studies were conducted to determine the impact of heavy metals in sludge-fertilized corn silage on the food and feed chain when the silage containing up to 5.26 mg Cd/kg was fed to dairy goats and feeder lambs.

Neither health nor performance of the goats or lambs were significantly affected when the high Cd corn silage was fed continuously for approximately one half of their productive lives. Consuming approximately 5 mg Cd and 100 mg Zn/day did not cause the metals to be secreted into milk of the lactating goats. Only Zn and Cd accumulated in the animals and only in liver and kidneys.

17. KEY WORDS AND DOCUMENT ANALYSIS

a. DESCRIPTORS	b. IDENTIFIERS/OPEN ENDED TERMS	c. COSATI Field/Group

18. DISTRIBUTION STATEMENT	19. SECURITY CLASS (This Report)	21. NO. OF PAGES
RELEASE TO PUBLIC	Unclassified	54
	20. SECURITY CLASS (This page) Unclassified	22. PRICE

EPA Form 2220-1 (Rev. 4-77) PREVIOUS EDITION IS OBSOLETE

DISCLAIMER

Although the information described in this article has been funded wholly or in part by the United States Environmental Protection Agency through assistance agreement number EPA-80-D-X0428 to U.S. Department of Agriculture ARS, it has not been subjected to the Agency's required peer and administrative review and therefore does not necessarily reflect the views of the Agency and no official endorsement should be inferred.

FOREWORD

The U.S. Environmental Protection Agency was created because of increasing public and government concern about the dangers of pollution to the health and welfare of the American people. Noxious air, foul water, and spoiled land are tragic testimonies to the deterioration of our natural environment. The complexity of that environment and the interplay of its components require a concentrated and integrated attack on the problem.

Research and development is that necessary first step in problem solution, and it involves defining the problem, measuring its impact, and searching for solutions. The Municipal Environmental Research Laboratory develops new and improved technology and systems to prevent, treat, and manage wastewater and solid and hazardous waste pollutant discharges from municipal and community sources, to preserve and treat public drinking water supplies, and to minimize the adverse economic, social, health, and aesthetic effects of pollution. This publication is one of the products of that research and is a most vital communications link between the researcher and the user community.

This report contains information obtained in a study to determine the potential animal and human health impacts of using municipal sludge to produce corn for silage.

Francis T. Mayo
Director
Municipal Environmental Research
Laboratory

ABSTRACT

Studies were conducted to document the impact of sludge-fertilized corn on the food and feed chain under controlled experimental conditions that eliminated any direct ingestion of sewage sludge. Specifically, the studies were to determine whether sludge-borne heavy metals that accumulate in corn are secreted into the milk of dairy goats or are accumulated in the organs and muscle of goats or market lambs consuming corn silage containing up to 5.26 mg cadmium (Cd)/kg.

Dry matter intake, milk production, and feed efficiency of dairy goats were not reduced by feeding a high-Cd corn silage continuously for 3 years --approximately half of their productive lives. Likewise, feed efficiency and daily gains of market lambs were not reduced by consuming high-Cd silage.

Cadmium and zinc (Zn) from corn silage were not secreted into the milk from lactating goats, even though some animals were receiving approximately 5 mg Cd and 100 mg Zn/day. In contrast, copper (Cu) concentrations were higher in milk from goats receiving the control feed.

The Cd concentrations in livers of both goats and lambs were always lower in animals receiving the control feed. These levels increased as the amount of silage Cd increased. Accumulations of Cd in animal kidneys were 5 to 10 times greater than those observed in livers, but they followed the same general patterns. Cd concentrations in animal heart and muscle were low and not affected by treatment. Zn, the only other element found to accumulate in silage as a result of treatment, did not increase in animal liver, heart, and muscle, but it increased slightly in lamb kidney as a result of feeding Zn-enriched silage. The concentrations of 16 other elements in the various animal tissues were not consistently affected when the animals were fed sludge-fertilized corn silage.

This report was submitted in fulfillment of Interagency Agreement EPA-80-D-X0428 by U.S. Department of Agriculture under the partial sponsorship of the U.S. Environmental Protection Agency. This report covers the period June 10, 1976 to October 31, 1981, and work was completed as of October 31, 1981.

CONTENTS

Foreword iii
Abstract iv
Contents v
Tables vi

1. Introduction 1
2. Summary and Conclusions 3
3. Materials and Methods 6
   - Corn Silage Production 6
   - Goat Trials 6
   - Lamb Trials 8
   - Chemical Analyses 8
   - Silage Quality 9
   - Statistical Analyses 9
4. Results and Discussion 10
   - Corn Silage 10
     - Production 10
     - Quality 10
     - Composition 12
   - Goat Feeding Trials 12
     - Performance 12
     - Milk Composition 15
     - Blood Composition 18
     - Body and Organ Weights 21
     - Organ Composition 23
   - Lamb Feeding Trials 27
     - Performance 27
     - Blood Composition 29
     - Organ Composition 29
     - Feces Composition 37
     - Histological Observations 37

References 39

TABLES

Number		Page
1	Application rates and elemental content of waste activated sewage sludge applied to a Waukegan silt loam soil	7
2	Yields (total dry matter) and compositional analyses of corn silage grown on sludge-amended soils	11
3	Elemental content of corn silage grown on sludge-amended soils	13
4	Performance data of female goats fed corn silage grown on sludge-amended soils	14
5	Elemental content of milk collected from female goats fed corn silage grown on sludge-amended soils	16
6	Elemental content of colostrum collected from female goats fed corn silage grown on sludge-amended soils	19
7	Elemental content of blood collected from goats fed corn silage grown on sludge-amended soils	20
8	Body and organ weights and blood data for female goats fed corn silage grown on sludge-amended soils (following 3 years of feeding)	22
9	Elemental content of liver collected from female goats fed corn silage grown on sludge-amended soils (following 3 years of feeding)	24
10	Elemental content of kidney collected from female goats fed corn silage grown on sludge-amended soils (following 3 years of feeding)	24
11	Elemental content of heart collected from female goats fed corn silage grown on sludge-amended soils (following 3 years of feeding)	25
12	Elemental content of muscle collected from female goats fed corn silage grown on sludge-amended soils (following 3 years of feeding)	25

TABLES (continued)

Number		Page
13	Performance data of lambs fed corn silage grown on sludge-amended soils	28
14	Elemental content of blood collected from lambs fed corn silage grown on sludge-amended soils	30
15	Elemental content of liver collected from lambs fed corn silage grown on sludge-amended soils	31
16	Elemental content of kidney collected from lambs fed corn silage grown on sludge-amended soils	32
17	Elemental content of heart collected from lambs fed corn silage grown on sludge-amended soils	33
18	Elemental content of muscle collected from lambs fed corn silage grown on sludge-amended soils	34
19	Elemental content of feces collected from lambs fed corn silage grown on sludge-amended soils	38

SECTION 1

INTRODUCTION

Use of municipal sewage sludges as a source of plant nutrients is of current interest because of economic and environmental concerns. Applications of sludge to soil at rates consistent with the nutrient requirements of a crop are believed to be most beneficial (Dowdy et al., 1976). Sommers (1977) stated that using sludge as a crop fertilizer would not greatly affect the demand for fertilizer in the United States because the total amount of sludge produced would supply only 1% to 2% of the annual nitrogen (N) required for crop production. But the impact of sludge addition to any given land area is significant where applications are feasible. Occurring along with the essential plant nutrients present in sludge are also nonessential elements or those potentially toxic to crops, animals, or humans.

Heavy metals are typically present in municipal sludges. Transfer of metals from sludge to soil and subsequently to plants that enter the food and feed chain present a significant health concern. Animals exposed to subclinical levels of heavy metals are not easily identified and may be slaughtered or used as a source of milk. Limited information is available concerning the effects of feeding sludge-fertilized crops to large ruminants (Bertrand et al., 1980; Decker et al., 1980; Fitzgerald, 1980; Heffron et al., 1980). These investigators have shown varying degrees of metal accumulation in animal liver and kidney, though the exact intake of sludge-borne metal was not known in each case. Most studies of this type have involved direct ingestion of sewage sludge, either as a component of the ration or as an adherient to leaf surfaces of forages.

Miller et al. (1967) and Sharma et al. (1979) spiked the diet of Holstein cows with $CdCl_2$ and found no accumulations of Cd in milk. Earlier findings lead Neathery and Miller (1975) to conclude that only minute amounts of Cd are secreted into milk. This finding agrees with that of Fitzgerald (1980), who showed that concentrations of trace metals in milk from cows grazing on sludge-irrigated pastures did not increase.

The purpose of the present studies was to document the impact of sludge-fertilized corn on the food and feed chain under controlled experimental conditions that eliminated the possibility of direct ingestion of sewage sludge. Specific

objectives were to answer the following questions:

1. Does the feeding of sludge-fertilized corn silage affect the long-term performance of dairy goats and market lambs?

2. Are sludge-borne heavy metals that accumulate in corn secreted into the milk of dairy goats fed the silage for 3 consecutive years?

3. Does cadmium (Cd) accumulate in the organ and muscle tissues of the dairy goats and market lambs that consumed corn silage containing high concentrations of Cd?

Determination of the effects on human health of consuming food products from animals that were fed sludge fertilized corn silage was not included in this study.

SECTION 2

SUMMARY AND CONCLUSIONS

Animal performance and trace metal accumulations were measured in the milk, blood, liver, kidney, heart, and muscle of dairy goats and market lambs fed corn (Zea mays L.) silage grown on sludge-amended and conventionally fertilized soil. The silage, containing high levels of bioaccumulated Cd (up to 5.26 mg/kg), was grown for 3 years on soil initially amended with 0, 30, 60, and 90 megagrams (Mg)/ha of sewage sludge. Before the second and third cropping, sludge was applied at rates of 0, 15, 30, and 45 Mg/ha. Zinc was the only other metal to accumulate in the silage. Its accumulation was proportionally less than Cd, which resulted in Zn:Cd ratios as low as 20. Soil pH ranged from 6.1 to 6.6 throughout the study. Silage dry matter production ranged from 16.7 to 19.6 Mg/ha and did not vary with treatment or between years. Silage quality, as measured by in vitro digestible dry matter (IVDDM), cell wall constituents, acid detergent fiber and lignin, and silica accumulations were not significantly affected by sludge applications.

Total dry matter intake, daily milk production, and feed efficiency (kg milk/kg feed) of dairy goats were not reduced by feeding a high-Cd corn silage continuously for 3 years (approximately half of their productive lives). The silage constituted >90% of the animal ration. Market lambs fed sludge-fertilized corn silage tended to have higher daily gains than did lambs fed control silage. Feed efficiency of lambs averaged 0.15 kg gain/kg feed for years II and III and was three times higher than values reported in the literature.

Though each lactation period was broken into 5- to 20- day sampling intervals, no significant differences ($P > 0.05$) in milk composition were observed from one sampling interval to another. Cadmium from the corn silage was not secreted into the milk from lactating goats, even though some animals were receiving approximately 5 mg Cd/day. Zinc concentrations of milk from control animals did not differ ($P > 0.05$) from those of goats fed sludge-fertilized corn silage when averaged across all sludge treatments. But Zn levels in milk decreased as increased sludge was applied within sludge treatments. In contrast to Zn, Cu concentrations were higher in milk from control goats than in milk from animals receiving various sludge treatments. The bioavailability of Cu may have been limited by the elevated

levels of Cd in silage from sludge treatments.

The elemental concentrations of 15 other metals and minerals in milk were not affected by treatment or time within the lactation period. Though colostrum generally contained higher concentrations of most minerals, no treatment effects were observed. As was true with milk composition, Cu was the only element in goat blood that was consistently affected by treatment. Copper levels in blood were lower for goats fed sludge-produced silage even though all animals received a Cu-containing trace mineralized salt ad libitum. This trend in blood Cu levels was not observed for lambs in any of the 3 test years.

The Cd concentrations in livers of both goats and lambs were always higher in animals fed Cd-containing silage, and they increased with increasing sludge applications. This result was particularly true for lambs during years II and III, when Cd concentrations as high as 5.29 mg/kg were found. Accumulations of Cd in animal kidneys were 5 to 10 times greater than those observed in livers, but they followed the same general patterns. A pronounced linear increase in lamb kidney and liver Cd with increased levels of silage Cd was in contrast to the plateau in Cd concentrations noted for the same goat tissues with increased Cd levels in the silage. Cadmium concentrations in animal heart and muscle were low and not affected by treatment.

Zinc, the only other element found to accumulate in silage as a result of treatment, did not increase in animal liver, heart, and muscle as a result of feeding Zn-enriched silage. In the case of lamb kidney, an increased Zn content was observed for animals fed sludge-fertilized corn silage. The increases were small but significant.

Copper concentrations in goat and lamb kidneys and goat livers were lower for animals fed sludge-fertilized silage than for animals consuming silage fertilized in a conventional manner. These reduced-Cu concentrations were postulated to result from the antagonistic blocking of the protein needed for Cu absorption by elevated Cd levels in the tissue.

The concentrations of 15 other elements in the various animal tissues were not consistently affected by sludge fertilization of corn silage. In addition, the measured concentrations were comparable to values reported in the literature, though reported data are minimal.

Study results showed that corn silage produced on soil amended at moderate to high rates with sewage sludge containing high levels of bioaccumulated Cd can be fed to dairy goats and market lambs as >90% of their ration without impairing their performance. Trace metals (particularly Cd) taken up by the corn and ingested by the animals did not accumulate in milk or muscle

tissue --foods consumed directly by humans. Cadmium did accumulate in the kidneys of goats and lambs, reaching concentrations of 25 mg Cd/kg of tissue when corn silage containing as much as 5.26 mg Cd/kg (an ingestion rate of approximately 5 mg Cd/day) was consumed continuously for 3 years. Livers of both species accumulate less Cd. Though Zn is taken up by corn to a smaller extent than Cd, it did accumulate in lamb kidneys, but not in goat kidneys or livers of either species. Histological examinations of lamb livers and kidneys showed no observable morphological differences as a result of consuming Cd-enriched silage.

SECTION 3

MATERIALS AND METHODS

CORN SILAGE PRODUCTION

The soil to which the sludge was applied was a well-drained, Typic Hapludoll (Waukegan) with a pH=6.2. It was a uniform silt loam material overlying neutral to calcareous outwash sand and gravel at approximately 60 cm depth. Waste activated sewage sludge filter cake was applied initially at rates of 0, 30, 60, or 90 Mg/ha (dry matter equivalent) on 0.22 ha plots. Prior to the second and third croppings, sludge was applied at rates of 0, 15, 30, and 45 Mg/ha. These treatments will hereafter be referred to as the control, low, medium, and high treatments, respectively. The applied sludge was immediately plowed into the surface 0.15 m of soil. Since sewage sludge does not contain adequate K for maximum corn production, all areas received an annual application of 60 kg K/ha. In addition, the control treatment received 200 kg N/ha and 25 kg P/ha for maximum crop production. Treatments were replicated four times in a randomized block design.

Elemental analyses (105 C wt. basis) of the sewage sludge are presented in Table 1. Although variations in sludge metal concentrations existed from year to year, they were near median concentrations reported for sludges in the North Central Region of the United States (Sommers, 1977), with the exception of Cd that ranged from 105 to 186 mg/kg. Because year I sludge was conditioned with lime to aid with filtration, a chemically equivalent amount of elemental S was applied to neutralize the added lime.

The corn was harvested during the hard dent stage of development as fodder silage and ensiled in 1.83 m by 3.66 m, polyethylene-lined temporary silos.

GOAT TRIALS

In each of 3 years, Alpine and Lamancha dairy goats were fed corn silages grown on sludge amended soil. In year I, goats were allotted to eight pens, two pens per treatment, in a randomized block (breed) design. Animals received the same treatment corn silage continuously for 3 years.

TABLE 1. APPLICATION RATES AND ELEMENTAL CONTENT OF WASTE ACTIVATED SEWAGE SLUDGE APPLIED TO A WAUKEGAN SILT LOAM SOIL.

ITEM	YEAR I TREATMENT CONTROL	LOW	MEDIUM	HIGH	S+	YEAR II TREATMENT CONTROL	LOW	MEDIUM	HIGH	S	YEAR III TREATMENT CONTROL	LOW	MEDIUM	HIGH	S
APPLICATION RATE			Mg/ha++					Mg/ha					Mg/ha		
ANNUAL	0	30	60	90		0	15	30	45		0	15	30	45	
CUMULATIVE	0	30	60	90		0	45	90	135		0	60	120	180	
ELEMENT			g/kg++					g/kg					g/kg		
NA	---	0.64	0.64	0.62	0.051	---	0.63a	0.64	0.72	0.049	---	0.62	0.56	0.58	0.032
K	---	0.54	0.50	0.50	0.027	---	0.84b	0.80	0.73	0.049	---	0.95b	1.05	1.22	0.113
CA	---	57.78	63.16	59.42	6.626	---	16.11a	15.50	15.35	0.394	---	37.66a	38.99	46.70	4.524
MG	---	3.29	3.55	3.28	0.250	---	2.26	2.20	2.14	0.077	---	3.23b	3.31	4.18	0.407
P	---	8.88	8.76	8.45	0.333	---	7.99b	8.34	8.66	0.211	---	11.37	11.53	11.41	0.582
FE	---	8.33	8.24	8.16	1.069	---	6.95b	7.48	7.77	0.319	---	12.45	12.38	11.79	0.430
AL	---	5.33	5.99	4.93	1.034	---	6.08a	6.89	8.20	1.065	---	13.22	13.09	12.74	0.348
			ug/kg++					ug/kg					ug/kg		
ZN	---	1701	1590	1674	136.0	---	2064bc	2581	2678	123.0	---	1624	1568	1605	63.0
MN	---	215	202	210	16.0	---	112a	105	106	4.0	---	255	269	287	22.0
B	---	29	31	38	6.0	---	20	24	19	6.0	---	18	20	18	2.0
CU	---	703	712	717	34.0	---	640a	629	730	53.0	---	711	699	653	40.0
PB	---	1255	1000	1303	219.0	---	608bd	819	828	40.0	---	443	425	404	27.0
CR	---	690	656	691	26.6	---	816b	750	765d	14.27	---	1012	978	993	54.7
NI	---	273	234	265	26.0	---	288bd	168	196	18.0	---	224	240	225	23.0
CD	---	158	161	156	14.0	---	186bd	133	137	7.0	---	108	105	112	5.0
AS	---	1.79	1.44	2.00	---	---	1.35	1.75	2.20	---	---	1.80	1.75	1.38	---
SE	---	0.69	0.69	0.73	---	---	0.62	0.73	0.70	---	---	0.71	0.69	0.68	---
HG	---	4.13	4.12	3.76	---	---	4.53	4.15	5.23	---	---	7.04	5.91	6.72	---

+ STANDARD DEVIAION
++ 105 C WEIGHT BSIS
a LINEAR EFFECT WITHIN SLUDGE LEVELS (P<0.05)
b LINEAR EFFECT WITHIN SLUDGE LEVELS (P<0.01)
c QUADRATIC EFFECT WITHIN SLUDGE LEVELS (P<0.05)
d QUADRATIC EFFECT WITHIN SLUDGE LEVELS (P<0.01)

Goats were fed silage ad libitum. In year I, supplemental urea was fed at 5 g/head-day during the nonlactation peiod. In years II and III, and during lactation in year I, goats received 0.315 kg soybean meal/head-day. Free choice trace mineral salt that contained <0.2 mg Cd, 2.4 mg Cr, 128 mg Cu, and 125 mg Zn/kg was offered throughout the trial.

At freshening, colostrum samples were collected from each goat and saved for elemental analyses. Goats were hand milked twice daily and milk weights were recorded at each milking. Milk samples were collected from each goat twice weekly, composited into 5, 25-day samples and analyzed for elemental composition. Blood samples were collected from the jugular vein of each goat at the end of each lactation, and freezedried for elemental analysis. At the end of lactation in the third year, animals were sacrificed and wet organ weights taken. After necropsy, individual organs were weighed and freeze-dried for analysis for elemental content.

LAMB TRIALS

In each of 3 years, corn silage, grown on soils amended annually with sludge was fed to 32 lambs that were allotted to 8 pens of 4 animals each in a randomized block design of 2 blocks per treatment. In years I and III, animals were assigned by breed, (Columbia and Hampshire crossbreds, year I; and Hampshire and Hampshire crossbreds, year III). In year II, animals were assigned by sex (ewes and whethers). Lambs were fed diets composed of corn silage ad libitum and 0.23 kg soybean meal for 102, 106, and 112 days in years I, II, and III, respectively. Free choice trace mineral salt that contained <0.20 mg Cd, 2.4 mg Cr, 128 mg Cu, and 125 mg Zn/kg was offered throughout the trial. Lambs were weighed at 2-week intervals while on trial. Blood was collected via jugular puncture from each lamb at the end of the feeding period, and freeze-dried for elemental analyses. At the termination of the feeding period, the lambs were sacrificed and tissues freeze-dried for elemental analyses.

CHEMICAL ANALYSES

Dried sewage sludge, corn silage, milk, blood, and animal organ samples were ground and ashed at 450°C for 24 hours (Dowdy et al., 1978). Ash from sludge, silage and milk samples were equilibrated with 2M HCl, while ash from blood and organ samples was equilibrated with 2M HNO_3. The supernatants were analyzed for Al, B, Ca, Cr, Cu, Fe, K, Mg, Mn, Na, Ni, P, Pb, and Zn by inductively coupled plasma (ICP) source emission spectroscopy. Separate samples were digested in HNO_3/H_2O_2 and analyzed by atomic absorption spectroscopy (AAS) for As and Se by hydride generation techniques (Freeman and Uthe, 1974) and for Hg by the cold vapor procedure (Melton et al., 1971).

Separate freeze-dried milk and organ samples were digested in

1.0M HNO_3, containing 1.5% $NH_4H_2PO_4$ and analyzed for Cd by flameless AAS utilizing continuous source (hydrogen lamp) background correction. Cadmium concentrations in sludge, silage, and blood were determined in the same manner by analyzing the 2.0M HNO_3 extract of the dried-ashed samples.

SILAGE QUALITY

Laboratory measures of quality included *in vitro* digestible dry matter (IVDDM) via the two-stage direct acidification method of the NC-64 Regional Committee (Marten and Barnes, 1979); chemical tests of Goering and Van Soest (1970), including detergent fiber, acid detergent lignin, and plant silica; and cell wall constituents via the takadiastase pretreatment procedure of Smith et al. (1982).

STATISTICAL ANALYSIS

All data were analyzed statistically by analysis of variance using the general linear model of SAS (statistical analysis system; Speed et al., 1978). Orthogonal contrasts were conducted to test significant differences between control and sludge treatments, and linear and quadratic effects within sludge levels. Standard deviations were calculated as the square root of the error mean squared.

SECTION 4

RESULTS AND DISCUSSION

CORN SILAGE

Production

Silage yields ranged from 16.7 to 19.6 Mg/ha dry matter (Table 2), and did not vary appreciably ($P > 0.05$) due to sludge applications, which reduced the possibilities for unwanted heterogeneity among treatments. The ratio of grain:stover decreased from 54 to 48 to 40% for year I, II, and III, respectively, as a result of increased plant populations (67,200 to 82,700 plants/ha) and variable weather conditions. Soil pH which remained essentially constant across all treatment years, ranged from 6.1 to 6.6, and was usually below the EPA (1979) regulation for maintaining soil pH at 6.5 or greater whenever food chain crops are grown on sludge amended soils.

Quality

Results of silage quality analyses are presented in Table 2. *In vitro* digestible dry matter (IVDDM) of corn silage did not vary significantly due to treatment (mean of 66.3%). This value is lower than the IVDDM value of 74.8% for corn silage grown on land irrigated with sewage effluent reported by Marten et al. (1980), but is similar to the *in vivo* DDM (64.0 $\pm$ 3.2%) for corn silage reported by Marten et al. (1975) for silage produced in a conventional manner.

Cell wall constituents (neutral detergent fiber) determined by the Smith et al. (1982) procedure averaged 46.6% and did not vary significantly as a result of sludge applications. This value is within the 48.3 $\pm$ 3.7% adjusted range from data reported by Marten et al. (1975) for corn silage grown by conventional agricultural practices (adjusted to account for residual starch remaining when the Goering and Van Soest, 1970, procedure was used by Marten et al., 1975).

Concentrations of acid detergent fiber in corn silage grown on sludge amended soil ranged from 27.0% (year I, medium) to 31.9% (year II, low) and were within the range of 28.8 $\pm$ 3.3% reported by Marten et al. (1975). The silica content of the silage averaged 2.3% which was slightly higher than the suggested

TABLE 2. YIELDS (TOTAL DRY MATTER) AND COMPOSITIONAL ANALYSES OF CORN SILAGE GROWN ON SLUDGE-AMENDED SOILS.

	YEAR I					YEAR II					YEAR III				
	TREATMENT					TREATMENT					TREATMENT				
ITEM	CONTROL	LOW	MEDIUM	HIGH	S+	CONTROL	LOW	MEDIUM	HIGH	S	CONTROL	LOW	MEDIUM	HIGH	S
YIELD:	Mg/ha++					Mg/ha					Mg/ha				
TOTAL DRY MATTER	18.86	18.40	17.91	18.72		17.49	17.44	18.31	18.96		17.67	16.73	19.60	18.98	
COMPOSITION:	g/kg++					g/kg					g/kg				
DRY MATTER	331	318	317	312	22.3	284	378	325	297	19.2	309	270	306	299	27.4
DIGESTIBLE DRY MATTER	616	621	622	641	20.9	656	657	656	673	18.0	686	705	707	709	30.9
CELL WALL CONTENTS	470	473	468	466	29.6	485	465	468	483	20.2	469	455	445	448	35.3
ACID DETERGENT FIBER	285	284	270	267	16.2	315	319	307	312	14.7	312	291	294	300	23.0
ACID DETERGENT LIGNIN	37	37	37	34	3.5	43	44	40	41	3.9	42	37	38	38	5.2
SILICA	29	27	24	23	3.4	23	24	23	24	4.5	18	18	19	19	3.3

+ STANDARD DEVIATION
++ 70 C WEIGHT BASIS
a CONTROL VS ALL SLUDGE LEVELS ($P<0.05$)
b CONTROL VS ALL SLUDGE LEVELS ($P<0.01$)
c LINEAR EFFECT WITHIN SLUDGE LEVELS ($P<0.05$)
d LINEAR EFFECT WITHIN SLUDGE LEVELS ($P<0.01$)
e QUADRATIC EFFECT WITHIN SLUDGE LEVELS ($P<0.05$)
f QUADRATIC EFFECT WITHIN SLUDGE LEVELS ($P<0.01$)

2% level above which optimal digestion by ruminant animals can be deterred (Goering and Van Soest, 1970).

Composition

The elemental composition data for corn silage presented in Table 3 show that Cd and Zn were the only elements that were increasead consistently as a result of sludge applications. Cadmium levels in corn plant tissue showed the largest relative increases and reached a high concentration of 5.26 mg/kg in silage produced on the high treatment during year III. Direct comparison of these data with literature values is difficult because most metal data are reported for separate plant parts. However, where comparable metal loading rates existed and the dilution effects of grain (low in metals) are considered, metal concentrations observed in this study were similar to those reported by Hinesly et al. (1977) and Kelling et al. (1977). The Cd content of silage was always high in that the National Research Council (1980) recommends that animal feeds not exceed 0.5 mg/kg of Cd for protection of the food chain against excessive ingestion of Cd.

Zinc concentrations in corn silage showed a linear ($P < 0.01$) increase with increased levels of sludge applications (Table 3). Silage Zn levels reached a high of 113 mg/kg during year II and were essentially the same for year III. As a consequence of the near constant tissue Zn levels for years II and III, Zn:Cd ratios decreased from 34 to 26 to 20 for the high treatment in years I, II, and III, respectively. These ratios were not only low, but the potential for Cd absorption also increased with time, because Zn may inhibit Cd absorption from the intestine of animals (Chaney, 1980).

Other elements in the corn silage (Table 3) were not greatly affected by sludge application. Similar trends were observed for leaf samples taken when the corn was silking (Dowdy et al. 1981). In a few instances, significant changes in elemental composition occurred for a given element during a specific year. The most prominent example was a slight increase in the Cu content of silage for years I and III as a result of sludge application. However, Cu was available *ad libitum* to all animals in a mineral salt supplement.

GOAT FEEDING TRIALS

Performance

Goat performance data presented in Table 4 show that total dry matter intakes did not differ ($P > 0.05$) among treatments in any of the 3 years, approximately one-half of their productive life. Intake of dry matter ranged from 0.84 to 1.67 kg and was generally lower in year I due to a lack of protein supplementation (soybean meal) during the nonlactation period.

TABLE 3. ELEMENTAL CONTENT OF CORN SILAGE GROWN ON SLUDGE-AMENDED SOILS.

	YEAR I					YEAR II					YEAR III				
	TREATMENT					TREATMENT					TREATMENT				
ITEM	CONTROL	LOW	MEDIUM	HIGH	S+	CONTROL	LOW	MEDIUM	HIGH	S	CONTROL	LOW	MEDIUM	HIGH	S
ELEMENT	g/kg++					g/kg					g/kg				
N	13.7	13.4	14.3	14.3	0.8	14.1	13.1	13.2	13.1	1.1	13.4	12.9	12.9	13.5	1.2
K	11.6	11.7	12.7	12.7c	0.8	12.5	11.7	10.8	11.9	1.6	10.7	10.5	10.6	11.5	0.9
CA	3.2	3.2	3.2	3.4	0.3	2.9	2.6	2.5	2.6	0.4	2.7	2.7	2.9	3.2c	0.3
MG	2.8	2.7	2.8	2.7	0.3	2.4b	1.9	1.8	1.9	0.4	2.2	2.1	2.0	2.1	0.3
P	2.4	2.2	2.5	2.5c	0.2	2.2b	1.7	1.6	1.9	0.3	1.8	1.7	1.7	1.9	0.2
	ug/kg++					ug/kg					ug/kg				
FE	192.1	170.8	155.0	177.8	56.73	276.3b	166.5	162.3	162.2	70.31	255.1	150.7	141.3	178.0	91.65
AL	68.1	65.9	69.8	90.3d	14.22	51.2	53.0	63.0	48.7f	7.72	59.4	46.8	63.5	46.8e	11.08
ZN	30.6b	39.9	49.6	58.6d	6.10	43.8a	52.0	67.1	112.6d	32.05	34.5b	73.5	74.6	107.0d	14.56
MN	47.0	43.2	45.2	53.6d	5.27	35.0	32.0	27.3	38.0	5.64	33.3	31.1	27.7	32.8	4.02
NA	11.8	9.8	10.7	10.0	3.90	18.4	15.8	16.8	15.7	6.38	23.5	7.7	47.4	35.3e	23.33
B	5.0	5.0	4.9	5.0	0.31	5.3	5.2	5.2	5.3	0.62	5.7	5.6	5.9	5.8	1.01
CU	3.6b	3.9	4.4	4.4c	0.36	3.5	3.7	3.8	3.6	0.54	4.2a	4.1	4.8	5.3d	0.44
PB	1.2	<0.9	0.8	0.9	----	1.1	1.3	1.1	1.2	0.27	1.2	1.1	2.4	1.6e	0.83
CR	1.6	1.4	1.2	1.1	0.50	0.7	0.8	0.8	1.1	0.33	0.9	0.4	1.0	0.9	0.48
NI	2.7	3.3	1.7	2.3e	0.86	0.7b	0.9	1.1	1.4d	0.28	0.6	0.4	0.9	1.0c	0.42
CD	<0.02b	0.71	1.27	1.73d	0.29	<0.20b	1.84	2.68	4.25d	0.77	<0.06b	1.39	2.73	5.26d	0.70
AS											<0.05	<0.06	<0.05	<0.05	----
SE											0.60	0.75	1.04	0.49	----
HG											<0.05	<0.05	<0.05	<0.05	----

\+ STANDARD DEVIATION
++ 70 C WEIGHT BASIS
a CONTROL VS ALL SLUDGE LEVELS (P<0.05)
b CONTROL VS ALL SLUDGE LEVELS (P<0.01)
c LINEAR EFFECT WITHIN SLUDGE LEVELS (P<0.05)
d LINEAR EFFECT WITHIN SLUDGE LEVELS (P<0.01)
e QUADRATIC EFFECT WITHIN SLUDGE LEVELS (P<0.05)
f QUADRATIC EFFECT WITHIN SLUDGE LEVELS (P<0.01)

TABLE 4. PERFORMANCE DATA OF FEMALE GOATS FED CORN SILAGE GROWN ON SLUDGE-AMENDED SOILS.

	YEAR I					YEAR II					YEAR III				
	TREATMENT					TREATMENT					TREATMENT				
ITEM	CONTROL	LOW	MEDIUM	HIGH	S+	CONTROL	LOW	MEDIUM	HIGH	S	CONTROL	LOW	MEDIUM	HIGH	S
NO. OF GOATS	9	5	8	10		8	4	6	10		7	4	6	9	
LACTATION DAILY FEED (KG DRY MATTER/HEAD)++															
CORN SILAGE	0.935	0.755	0.685	0.735	-----	1.357	1.017	0.957	1.297	-----	1.157	0.957	1.017	0.967	-----
SOYBEAN MEAL	0.315	0.315	0.315	0.315	-----	0.313	0.313	0.313	0.313	-----	0.313	0.313	0.313	0.313	-----
TOTAL	1.250	1.070	1.000	1.050	0.133	1.670	1.330	1.270	1.610	0.137	1.470	1.270	1.330	1.280	0.140
NONLACTATION DAILY FEED (KG DRY MATTER/ HEAD)++															
CORN SILAGE	0.995	0.835	0.865	0.905	-----	1.057	0.937	0.907	1.037	-----	1.087	0.907	0.857	0.907	-----
SOYBEAN MEAL	0.005	0.005	0.005	0.005	-----	0.313	0.313	0.313	0.313	-----	0.313	0.313	0.313	0.313	-----
TOTAL	1.000	0.840	0.870	0.910	0.125	1.370	1.250	1.220	1.350	0.073	1.400	1.120	1.170	1.120	0.142
MILK PRODUCTION (KG/DAY)	1.68	1.42	1.52	1.70	0.783	1.53	1.07	1.42	1.31	0.579	1.24	0.54	1.35	1.27de	0.624
FEED EFFICIENCY (KG MILK/KG FEED)	1.36	1.36	1.51	1.62	0.739	0.95	0.71	1.02	0.85e	0.522	1.01a	0.20	1.04	0.91df	0.574

+ STANDARD DEVIATION
++ DURING YEAR I GOATS RECEIVED 5G UREA/HEAD/DAY FOR THE NONLACTATION PERIOD AND WERE FED 0.315KG SOYBEAN MEAL/HEAD/DAY DURING LACTATION PERIODS. IN SUBSEQUENT YEARS GOATS WERE FED 0.313KG SOYBEAN MEAL/HEAD/DAY DURING BOTH LACTATION AND NONLACTATION PERIODS.
a CONTROL VS ALL SLUDGE LEVELS ($P<0.05$)
d LINEAR EFFECT WITHIN SLUDGE LEVELS ($P<0.01$)
e QUADRATIC EFFECT WITHIN SLUDGE LEVELS ($P<0.05$)
f QUADRATIC EFFECT WITHIN SLUDGE LEVELS ($P<0.01$)

The lack of significant differences in dry matter intake between treatments agrees with the findings of Decker et al. (1980) where forage acceptability by beef cattle was not generally impaired by sludge applications to mowed tall fescue 21 days before grazing.

Daily milk production (kg) for years I, II, and III averaged 1.48 (control), 1.01 (low), 1.43 (medium), and 1.43 (high), respectively (Table 4), and did not differ significantly between breeds, nor between control and the average of sludge treatments. In year III, milk production increased ($P < 0.01$) between treatments as sludge application rate increased. This trend, although not significant, was also observed in years I and II, and may have been due to poorer milking ability of goats allotted to the low treatment.

Feed efficiency (kg milk/kg feed) in year I averaged 1.46 and was not affected ($P > 0.05$) by treatments; however, in year II a significant quadratic ($P < 0.05$) effect of increasing sludge application on feed efficiency was observed, that was caused by the production of more milk per unit dry matter feed intake by goats in the medium treatment. In year III, feed efficiency of goats fed control corn silage was significantly higher ($P < 0.05$) than that of goats fed sludge-fertilized corn silage. As with milk production, increased feed efficiency ($P < 0.01$) with increased sludge applications was observed for goats within sludge treatments during year III. This phenomenon probably resulted from the unusually low quantities of milk produced by goats in the low treatment.

Milk Composition

Concentrations of trace elements in milk of various species have been reviewed by Archibald (1958). Dairy goats were used because of their convenient size and as a representative of the ruminant species. Gross composition of goat's and cow's milk is similar (Larson, 1978). Parkash and Jenness (1968) noted that goat milk contained less lactose, higher pyrimidine nucleotides, and more C_{10} fatty acids than milk from cows. Elemental concentrations of goat milk dry matter (DM) are presented in Table 5. These are averages of values obtained for the five sampling periods. There were no significant ($P > 0.05$) differences among sampling periods in any of the 3 years.

Cadmium, the major trace metal that was bioaccumulated in the corn silage, was not transferred into milk ($P > 0.01$) from lactating goats (Table 5), even though animals on the high treatment consumed silage that contained in excess of 5 mg Cd/kg (approximately 5.0 mg Cd/day). The Cd concentration in milk from goats fed the highest level of dietary Cd was only 0.009 mg/kg (approximately 0.001 mg/L on a fluid basis). This value is considerably lower than the 0.027 mg/L median Cd value for bovine milk reported by Pinkerton et al. (1973), but is of the same order of magnitude noted by Miller et al. (1967) for hand milked

TABLE 5. ELEMENTAL CONTENT OF MILK COLLECTED FROM FEMALE GOATS FED CORN SILAGE GROWN ON SLUDGE-AMENDED SOILS.

	YEAR I					YEAR II					YEAR III				
	TREATMENT					TREATMENT					TREATMENT				
ITEM	CONTROL	LOW	MEDIUM	HIGH	S+	CONTROL	LOW	MEDIUM	HIGH	S	CONTROL	LOW	MEDIUM	HIGH	S
NO. OF GOATS	9	5	8	10		8	4	6	10		7	4	6	9	
ELEMENT	g/kg++					g/kg					g/kg				
N	39.09	43.06	40.25	38.21d	4.414	38.74	40.29	37.71	39.67	4.773	39.85	42.66	37.22	38.93	8.844
NA	2.04	2.12	2.30	1.89e	0.694	2.79a	2.54	1.97	2.15	1.257	2.74	2.76	2.45	2.67	1.175
K	12.93	13.87	12.93	12.51d	2.295	10.86	11.09	10.91	10.91	2.835	11.25	11.31	12.54	11.01	4.600
CA	8.51	9.19	8.47	8.67ce	0.943	8.69b	10.29	9.00	8.66d	1.184	10.26	10.18	9.65	9.92	1.710
MG	0.89	0.90	0.88	0.87	0.124	0.87	0.87	0.88	0.88	0.164	0.91	0.91	0.98	0.89	0.214
P	7.16b	8.07	7.46	7.24d	0.938	6.80a	7.81	7.03	6.92d	0.872	7.24	7.46	6.88	6.90c	0.888
	mg/kg++					mg/kg					mg/kg				
FE	2.52b	2.30	2.30	2.13	0.555	2.76	4.45	2.78	2.49d	2.076	3.41	3.55	2.76	2.69c	1.609
AL	<0.10	<0.10	<0.10	<0.11	-----	<0.72	<0.55	<0.37	<0.61	-----	6.25	7.62	6.88	6.19e	2.665
ZN	35.07	37.22	33.81	30.76d	5.611	34.07	40.77	34.54	32.85d	7.132	39.45	40.12	34.60	36.94	12.862
MN	<0.25	<0.23	0.28	<0.31	-----	0.29	0.36	0.31	0.27d	0.124	0.30	0.32	0.24	0.21d	0.115
B	2.30b	2.15	2.05	2.03	0.574	1.94	1.74	1.62	1.84	0.521	1.63	1.41	1.61	1.68	0.738
CU	0.42	0.32	0.29	0.28	0.397	0.79	0.63	0.58	0.53	0.520	0.64b	0.43	0.26	0.29	0.415
PB	1.05	<1.06	1.03	<0.85	-----	<0.50	<0.50	<0.50	<0.50	-----	<0.33	<0.35	<0.31	<0.33	-----
CR	0.28b	0.37	0.30	0.33e	0.104	<0.50	<0.50	<0.50	<0.50	-----	0.42	0.43	0.37	0.41	0.124
NI	<0.15	<0.16	<0.15	<0.14	-----	<0.50	<0.50	<0.50	<0.50	-----	<0.12	<0.13	<0.12	<0.12	-----
CD	<0.005	<0.005	<0.004	<0.003	-----	0.013	0.011	<0.009	0.009	-----	0.011	0.017	0.012	0.009c	0.013
AS	<0.03	<0.03	<0.02	<0.03	-----	<0.02	<0.02	----	<0.02	-----	<0.02	<0.03	<0.02	<0.02	-----
SE	<0.13	<0.15	<0.11	<0.13	-----	<0.03	0.06	----	<0.05	-----	0.22	0.22	0.20	0.22	-----
HG	0.05	0.06	0.05	0.05	0.021	<0.02	<0.02	----	<0.02	-----	<0.03	<0.05	<0.06	<0.06	-----

+ STANDARD DEVIATION
++ 70 C WEIGHT BASIS
a CONTROL VS ALL SLUDGE LEVELS (P<0.05)
b CONTROL VS ALL SLUDGE LEVELS (P<0.01)
c LINEAR EFFECT WITHIN SLUDGE LEVELS (P<0.05)
d LINEAR EFFECT WITHIN SLUDGE LEVELS (P<0.01)
e QUADRATIC EFFECT WITHIN SLUDGE LEVELS (P<0.05)
f QUADRATIC EFFECT WITHIN SLUDGE LEVELS (P<0.01)

cows.

The linear decrease in milk Cd with increased sludge applications (Year III) was probably an artifact that resulted from low milk production of animals of the low treatment. Lactating rats have a Cd-binding protein present in the mammary gland which effectively limits Cd transfer to milk (Lucis et al., 1972). If a similar protein exists in mammary tissue of lactating goats, it would explain the low Cd levels in milk. Dietary absorption of Cd from the gastrointestinal tract is thought to be low, but small amounts of Cd have been shown to be secreted into milk (Friberg et al., 1971; Miller et al., 1967; Neathery et al., 1974). However, as in our study, Fitzgerald (1980) did not observe Cd accumulation in milk from cows grazing forage irrigated with sewage sludge.

The Zn concentrations of milk from control goats did not differ ($P > 0.05$) from levels found in milk from goats fed sludge fertilized corn silage, when averaged across all sludge treatments. However, concentrations of Zn in milk decreased as amounts of applied sludge increased within sludge treatments (Table 5). This was significant in years I and II ($P < 0.01$) and occurred in spite of the fact that Zn concentrations in the silage ration increased with increasing sludge applications. Zinc concentrations ranged from 30.8 to 40.8 mg/kg milk DM, and are similar in magnitude to those reported by Fitzgerald (1980) for 8 to 15 year-old cows ingesting forage irrigated with sewage sludge. Zinc has been found in relatively large amounts in goat milk, but reported values are dependent on length of storage, presence of Fe, and exposure to air (Murthy and Rhea, 1968).

Control goats had higher concentrations of Cu in milk DM in each year, although significant ($P < 0.01$) only in year III, as the amount of sludge used as a fertilizer increased (Table 5). It is possible that increased levels of Cd and Zn in the corn silage from sludge fertilized soil caused Cu to be less readily absorbed by the goats. Chaney (1980), in a review article, has pointed out that enhanced levels of Zn, Cd, and/or Fe can reduce the bioavailability of Cu in ruminants. Although the levels of Fe in silage were not increased by sludge fertilization, both Cd and Zn concentrations were significantly higher in silages produced on sludge amended soil. All considerations concerning Cu accumulations must be viewed in the light that a Cu-containing mineralized salt was available to all animals, ad libitum, throughout the trial.

Lead contents of milk DM from goats fed control silage did not differ from that of goats fed corn silage fertilized with various amounts of sewage sludge. Average Cr concentrations in milk samples from goats in the present study were 0.5 mg/kg DM. Schroeder et al. (1963) reported that cow's milk contained 10 mg Cr/kg. Nickel concentrations in goat milk DM were always below the detection limit, which varied, but was <0.2 mg/kg during

years I and III. Information related to the normal Ni content of goat milk is limited, but values for bovine milk and colostrum have been reported to be 0.03 and 10 mg/kg DM, respectively (Kirchgessner, 1955, as cited by Archibald, 1958).

Iron concentrations of milk DM from goats ranged from 2.13 to 4.45 mg/kg, but were not consistently affected ($P > 0.05$) by sludge treatment. Iron contents of goat's milk ranged from 0.1 to 0.7 mg/L (Akinsoyin et al., 1979; Parkash and Jenness, 1968), which was equivalent to 0.8 to 5.8 g Fe/kg of milk DM. Aluminum in goat milk did not exceed 1 mg/kg during the first 2 years. The higher Al values observed for year III are not understood.

A linear ($P < 0.01$) decline in Mn content (Table 5) of goat milk was observed in years II and III for animals fed sludge fertilized corn silage as sludge application rates increased; however, Mn in milk from goats fed control corn silage did not differ ($P > 0.05$) from that of goats fed sludge fertilized silage when averaged across sludge treatments. Boron levels in milk were not significantly ($P > 0.05$) affected by treatments, although milk from control animals tended to have higher B concentrations. Arsenic, Se, and Hg in milk samples were near or below our detection limits, but, as with several other elements, were not increased in the corn silage as a result of sludge fertilization.

Elemental concentrations in colostrum (Table 6) were higher than in regular milk, as has been reported by Parkash and Jenness (1968) for bovine colostrum. Treatment had little effect on elemental composition of colostrum. However, in year I, Cu contents were 1.59, 1.96, 0.83, and 0.07 mg/kg for colostrum from goats on control, low, medium, and high treatments, respectively, with a significant ($P < 0.05$) decrease within sludge levels. Copper contents of colostrum in years II and III also decreased as amount of sludge used as a fertilizer increased.

Blood Composition

Elemental composition of goat blood DM collected yearly from the does is presented in Table 7. Concentrations of Cd in goat blood were not enhanced by feeding sludge fertilized corn silage that contained elevated levels of Cd. In years I and III, lower ($P < 0.05$ and $P < 0.01$, respectively) blood Cd concentrations were observed for animals on sludge treatments, although absolute differences were small. Cadmium concentrations in blood were <0.12 mg/kg DM after 3 years of feeding high Cd silage. Assuming blood to contain 20% solids, whole blood Cd levels were <24 µg/L, which falls near the range of 3.8 to 21.6 µg Cd/L reported by Dorn et al. (1973) for bovine blood. The significance of a lack of increased Cd in goat blood lies with the observations of Bernard et al. (1980) that ". . . blood Cd level mainly reflects current exposure." They observed a direct relationship ($r = 0.996$) between blood Cd and Cd concentration of drinking water for female rats exposed to water containing 2 to 200 µg Cd/L for

TABLE 6. ELEMENTAL CONTENT OF COLOSTRUM COLLECTED FROM FEMALE GOATS FED CORN SILAGE GROWN ON SLUDGE-AMENDED SOILS.

	YEAR I					YEAR II					YEAR III				
	TREATMENT					TREATMENT					TREATMENT				
ITEM	CONTROL	LOW	MEDIUM	HIGH	S+	CONTROL	LOW	MEDIUM	HIGH	S	CONTROL	LOW	MEDIUM	HIGH	S
NO. OF GOATS	9	5	8	10		8	4	6	10		7	4	6	9	
ELEMENT	g/kg++					g/kg					g/kg				
N	73.66	66.98	72.55	76.00	15.699	77.03	78.85	70.38	76.46	11.728	66.10	71.23	76.03	78.03	11.792
NA	2.50	2.61	2.52	1.77	1.718	2.96	5.88	1.61	2.62	2.673	2.21	4.27	3.31	4.06	2.683
K	4.77	3.42	4.12	5.07	1.465	3.84	3.45	3.18	4.30	1.086	5.43	4.63	5.65	3.89	2.199
CA	5.81	4.55	4.62	6.60c	1.397	8.72	9.48	6.22	9.12	6.964	7.79	7.72	6.99	9.64	3.014
MG	1.05	0.94	0.94	1.10	0.318	1.01	1.23	0.96	1.05	0.412	1.30	0.93	1.04	1.07	0.295
P	5.69	4.70	5.00	6.47c	1.180	6.79	7.42	4.65	7.25	3.980	6.82	6.08	5.89	7.40	1.916
	ug/kg++					ug/kg					ug/kg				
FE	4.78	5.17	3.40	3.43	2.118	5.31	6.80	3.33	4.45	2.074	5.45	2.95	2.25	9.94	7.873
AL	<0.10	<0.10	<0.10	<0.10	----	2.61	2.44	2.56	1.94	1.616	<0.62	<0.28	<0.25	<0.02	----
ZN	68.78	55.95	61.08	61.67	20.688	64.53	44.85	60.00	66.43	21.945	69.25	51.65	52.21	54.03	17.465
MN	0.52	0.44	0.36	0.35	0.331	0.18	0.10	0.12	0.14	0.066	0.26	0.25	0.17	0.14	0.097
B	0.64	0.59	0.49	0.57	0.214	0.88	0.91	0.50	0.69	0.543	0.64	0.72	0.73	0.91	0.375
CU	1.59	1.96	0.83	0.07c	1.154	2.91a	0.73	1.37	1.18	1.260	1.35	0.98	0.62	0.86	0.841
PB	1.41	<0.20	1.81	1.60	----	<0.50	<0.50	<0.50	<0.50	----	0.56	0.55	0.53	0.67	0.193
CR	0.40	0.24	0.34	0.19	0.201	<0.50	<0.50	<0.50	<0.50	----	0.35	0.27	0.28	0.30	0.092
NI	<0.38	0.32	0.16	<0.14	----	<0.50	<0.50	<0.50	<0.50	----	0.20	0.14	<0.06	<0.08	----
CD	<0.024	<0.005	<0.009	0.010	----	<0.002	<0.003	<0.022	0.005	----	0.007	0.005	<0.004	0.009	----
AS	<0.02	<0.01	<0.01	<0.02	----	<0.03	<0.03	<0.03	<0.03	----	<0.02	<0.02	<0.02	<0.02	----
SE	<0.15	0.16	<0.11	0.22	----	0.51	0.46	----	0.43	----	0.44	0.37	0.27	0.33	----
HG	0.07	0.07	0.09	0.08	0.018	<0.02	<0.02	----	<0.02	----	----	0.06	<0.05	<0.09	----

\+ STANDARD DEVIATION
++ 70 C WEIGHT BASIS
a CONTROL VS ALL SLUDGE LEVELS (P<0.05)
b CONTROL VS ALL SLUDGE LEVELS (P<0.01)
c LINEAR EFFECT WITHIN SLUDGE LEVELS (P<0.05)
d LINEAR EFFECT WITHIN SLUDGE LEVELS (P<0.01)
e QUADRATIC EFFECT WITHIN SLUDGE LEVELS (P<0.05)
F QUADRATIC EFFECT WITHIN SLUDGE LEVELS (P<0.01)

TABLE 7. ELEMENTAL CONTENT OF BLOOD COLLECTED FROM GOATS FED CORN SILAGE GROWN ON SLUDGE-AMENDED SOILS.

	YEAR I					YEAR II					YEAR III				
	TREATMENT					TREATMENT					TREATMENT				
ITEM	CONTROL	LOW	MEDIUM	HIGH	S+	CONTROL	LOW	MEDIUM	HIGH	S	CONTROL	LOW	MEDIUM	HIGH	S
NO. OF GOATS	9	5	8	10		8	4	6	10		7	4	6	9	
ELEMENT	g/kg++					g/kg					g/kg				
K	5.26	5.69	5.71	5.64	0.613	4.72	5.17	5.14	5.12	0.635	4.95	5.38	5.06	5.15	0.670
CA	0.37	0.36	0.36	0.37	0.031	0.36	0.38	0.38	0.37	0.030	0.35	0.36	0.35	0.33	0.043
MG	0.13	0.14	0.13	0.13	0.020	0.12	0.13	0.14	0.12	0.011	0.13	0.13	0.12	0.11	0.016
P	0.89	0.88	0.90	0.87	0.056	0.99	0.80	0.98	0.92	0.147	0.89	0.94	0.99	0.90	0.071
FE	2.13	2.16	2.12	2.17	0.201	1.79	1.80	1.78	1.69	0.198	1.77	1.76	1.70	1.69	0.146
	ug/kg++					ug/kg					ug/kg				
AL	<0.66	<0.30	<0.64	<0.13	----	3.09	3.38	3.26	2.86	0.828	3.14a	2.82	1.63	1.74	1.011
ZN	12.89	13.65	12.40	12.23	3.194	11.23	12.69	11.16	11.62	2.763	10.98	12.57	11.64	10.85	2.282
MN	<0.10	<0.10	<0.10	<0.10	----	<0.10	<0.10	<0.10	<0.10	----	<0.10	<0.14	<0.10	<0.10	----
B	4.33	2.42	3.10	3.49	1.514	0.81b	0.99	1.64	1.39cf	0.313	4.14b	3.60	3.51	3.06c	0.435
CU	5.04	4.73	4.45	4.53	0.648	6.44a	5.93	5.39	5.07	0.984	4.16b	3.46	2.81	2.12c	0.946
PB	<1.21	<1.00	<1.00	<1.12	----	<1.00	<1.00	<1.00	<1.00	----	<1.00	<1.00	<1.00	<1.00	----
CR	<0.14	<0.10	<0.10	<0.10	----	0.38	0.38	0.37	<0.31	----	<0.31	<0.66	<0.12	<0.10	----
NI	<0.30	<0.30	<0.30	<0.30	----	0.78	0.64	0.68	<0.56	----	0.46	0.72	<0.40	<0.34	----
CD	0.036a	0.018	0.033	0.025	0.011	0.012	0.010	0.010	0.013	0.009	0.011b	0.012	0.004	0.005c	0.004
AS	0.02	<0.02	<0.02	<0.02	----	<0.02	<0.02	<0.02	<0.02	----	<0.02	<0.02	<0.02	<0.02	----
SE	0.27	0.28	0.28	0.26	----	0.25	0.22	0.26	0.28	----	0.31	0.25	0.32	0.32	----
HG	----	----	----	----	----	<0.02	<0.02	<0.02	<0.04	----	<0.07	<0.08	<0.05	<0.02	----

\+ STANDARD DEVIATION
++ 70 C WEIGHT BASIS
a CONTROL VS ALL SLUDGE LEVELS (P<0.05)
b CONTROL VS ALL SLUDGE LEVELS (P<0.01)
c LINEAR EFFECT WITHIN SLUDGE LEVELS (P<0.05)
d LINEAR EFFECT WITHIN SLUDGE LEVELS (P<0.01)
e QUADRATIC EFFECT WITHIN SLUDGE LEVELS (P<0.05)
f QUADRATIC EFFECT WITHIN SLUDGE LEVELS (P<0.01)

3-plus months.

Zinc contents of blood DM from goats did not vary significantly among treatments in any of the 3 years and averaged 12.89 mg/kg (year I), 11.78 mg/kg (year II), and 11.5 mg/kg (year III). Even though Zn levels were up to 3X higher in sludge fertilized corn silage than in silage from the control treatment, there was no effect of treatment on blood levels of Zn. This lack of accumulation of Zn in the blood is consistent with the findings of Fitzgerald (1980) for dairy cows grazing forage irrigated with sewage sludge.

Copper contents of blood DM ranged from 6.44 mg/kg (control, year II) to 2.12 mg/kg (high, year III). In each year, control animals had higher concentrations of Cu in blood DM than animals fed corn silage grown on sludge fertilized soils. Also, there was a tendency for blood Cu to decrease as level of sludge applied increased. The observed Cu concentrations fall within the range reported by Underwood (1977) as normal for animals (0.5 to 1.5 mg/L). Copper contents of milk were also higher in control animals than in those fed sludge fertilized corn silage. It is possible that elevated goat tissue Cd and Zn levels interfered with Cu metabolism.

Lead concentrations in goat blood DM were <1.2 mg/kg, which translates into <0.25 mg/L if one assumes whole blood to contain 20% solids. Under normal conditions, goat blood Pb remains constant at 0.1 to 0.13 mg/L with approximately 90% of animal blood Pb associated with red blood cells (Neathery et al., 1974).

Chromium contents of blood DM were <0.4 mg/kg and were similar ($P > 0.05$) for all treatments. Nickel values for whole blood were <0.3 mg/kg DM (year I) and <0.8 mg/kg DM (years II and III) and were no greater than the mean Ni concentration of 3.5 mg/L reported by Sunderman et al. (1972) for goat blood.

Aluminum ranged from <0.7 to 3.4 mg/kg in goat blood and was not affected ($P > 0.05$) by treatment. Levels of blood Mn from goats averaged <0.1 mg/kg, while average B contents were 3.34 mg/kg (year I), 1.21 mg/kg (year II), and 3.58 mg/kg (year III). Lintzel (1931, as cited by Haenlein, 1980), reported Ca, Fe, Mg, K, and P concentrations in whole goat blood as 0.33, 0.382, 0.025, 0.97, and 0.173 g/kg DM, respectively. Contents of these elements in blood of animals in our study were similar in each of the 3 years and were not affected by treatments.

Body and Organ Weights

Body and organ weights are presented in Table 8. At the end of the third year, average body weights of goats fed corn silage from control, low, medium, and high treatments were 58.2, 62.7, 52.0, and 55.8 kg, respectively; there were no significant differences for animal body weights among treatments, or between

TABLE 8. BODY AND ORGAN WEIGHTS AND BLOOD DATA FOR FEMALE GOATS FED CORN SILAGE GROWN ON SLUDGE-AMENDED SOILS (FOLLOWING 3 YEARS OF FEEDING).

ITEM	TREATMENT				S+
	CONTROL	LOW	MEDIUM	HIGH	
NO. OF GOATS	7	4	6	9	
ANIMAL WEIGHT (KG)	58.2	62.7	52.0	55.8	10.78
ORGAN WEIGHTS (FRESH WEIGHT, G)					
KIDNEY	158.8	148.0	147.7	140.8	28.28
LIVER	1055.6	917.3	1027.1	937.4	210.49
LUNG	495.6	498.4	626.3	520.6	131.49
HEART	281.6	299.3	325.4	263.1	63.87
SPLEEN	278.5	298.4	203.3	291.1	104.67
HEMATOCRIT (%)	32.3	34.3	29.0	34.3e	4.83
HEMOGLOBIN (G/DL)	10.4	11.3	9.6	11.2e	0.15

\+ STANDARD DEVIATION
a CONTROL VS ALL SLUDGE LEVELS (P<0.05)
b CONTROL VS ALL SLUDGE LEVELS (P<0.01)
c LINEAR EFFECT WITHIN SLUDGE LEVELS (P<0.05)
d LINEAR EFFECT WITHIN SLUDGE LEVELS (P<0.01)
e QUADRATIC EFFECT WITHIN SLUDGE LEVELS (P<0.05)
f QUADRATIC EFFECT WITHIN SLUDGE LEVELS (P<0.01)

breeds (P >0.05).

Fresh kidney weights of control animals averaged 0.159 kg; this tended to be higher than average weights of kidneys from goats fed sludge fertilized corn silage. Liver weights of animals fed control corn silage averaged 1.056 kg and tended to be higher than liver weights from goats fed corn silage grown on sludge amended soil. Goat livers weighed more than the average 0.525 kg reported by Simpson (1945), but breed and age were not defined. However, neither the kidney nor liver weights of control animals were significantly different than weights of kidneys and liver from animals fed sludge fertilized corn silage.

Wet lung, spleen, and heart weights were not significantly affected by treatment, or between breed. Hematocrit (packed cell volume) values were 32.3, 34.3, 29.0, and 34.3% for goats fed control, low, medium, and high treatments, respectively (Table 8). All values are within the reported range for goats, 20-37% (Merck, 1973). Hemoglobin values for animals fed control, low, medium, and high silage were 1.04, 1.13, 0.96, and 1.12 g/L, respectively. Merck (1973) reported normal hemoglobin values for goats to range from 0.8 to 1.4 g/L.

Organ Composition

Elemental contents of tissues collected from goats are presented in Tables 9, 10, 11, and 12. Goats fed control, low, medium, and high corn silage for three years consumed approximately <7, 210, 375, and 535 mg Cd (year I); <9, 650, 905, and 1795 mg Cd (year II); and <25, 435, 910, and 1655 mg Cd (year III), respectively. Cadmium, the element that accumulated in the corn silage most dramatically, in goat livers of control, low, medium, and high treatments was 0.26, 1.72, 2.10, and 2.94 mg/kg, respectively. Liver Cd was less (P <0.01) for animals fed control corn silage, and Cd concentrations of goat livers from low, medium, and high treatments tended to increase as amount of sludge applied increased (Table 9). Kidney Cd concentrations were approximately 10 times higher than those observed in liver, ranging from 3.09 to 22.41 mg/kg for animals on control and high treatments, respectively. Kidney Cd levels for control animals were significantly (P <0.01) less than Cd levels of kidneys for animals fed sludge fertilized corn silage. The amount of Cd in kidneys from animals fed sludge fertilized corn silage increased linearly (P <0.05) with increasing applications of sludge. These trends are similar to those observed for lambs fed the same silage for a 100-day period.

Cadmium is absent from the human body at birth and accumulates with age up to about 50 years (Underwood, 1977), at which time one-half to two-thirds of the accumulated Cd occurs in liver and kidneys (Perry et al., 1965; Schroeder et al., 1961; W. H. O., 1973). Retention of Cd in liver and kidneys is in combination with the protein methallothionein (Margoshes et al.,

TABLE 9. ELEMENTAL CONTENT OF LIVER COLLECTED FROM FEMALE GOATS FED CORN SILAGE GROWN ON SLUDGE-AMENDED SOILS (FOLLOWING 3 YEARS OF FEEDING).

ITEM	TREATMENT				S+
	CONTROL	LOW	MEDIUM	HIGH	
NO. OF GOATS	7	4	6	9	
ELEMENT			g/kg++		
NA	2.93	2.81	2.73	2.80	0.439
K	8.91	8.77	7.77	8.49	1.323
CA	0.13	0.13	0.10	0.11	0.020
MG	0.57	0.47	0.42	0.46	0.158
P	10.92	11.01	10.18	10.88	1.338
FE	0.37	0.36	0.35	0.33	0.154
			mg/kg++		
AL	<0.93	<0.77	<0.35	<0.51	-----
ZN	90.34	91.25	85.88	88.82	22.389
MN	6.52	6.45	6.28	6.11	2.075
B	0.74	0.70	<0.35	0.60	-----
CU	16.64b	8.55	10.27	10.74	4.334
PB	<0.70	<0.60	<0.63	<0.64	-----
CR	<0.30	<0.30	<0.33	<0.31	-----
NI	<0.92	<0.34	<0.34	<0.35	-----
CD	0.26b	1.72	2.10	2.94	1.413

\+ STANDARD DEVIATION
++ 70 C WEIGHT BASIS
a CONTROL VS ALL SLUDGE LEVELS (P<0.05)
b CONTROL VS ALL SLUDGE LEVELS (P<0.01)
c LINEAR EFFECT WITHIN SLUDGE LEVELS (P<0.05)
d LINEAR EFFECT WITHIN SLUDGE LEVELS (P<0.01)
e QUADRATIC EFFECT WITHIN SLUDGE LEVELS (P<0.05)
f QUADRATIC EFFECT WITHIN SLUDGE LEVELS (P<0.01)

TABLE 10. ELEMENTAL CONTENT OF KIDNEY COLLECTED FROM FEMALE GOATS FED CORN SILAGE GROWN ON SLUDGE-AMENDED SOILS (FOLLOWING 3 YEARS OF FEEDING).

ITEM	TREATMENT				S+
	CONTROL	LOW	MEDIUM	HIGH	
NO. OF GOATS	7	4	6	9	
ELEMENT			g/kg++		
NA	11.98	11.70	12.11	8.89	2.425
K	11.07	11.24	11.27	10.05c	0.726
CA	0.48	0.52	0.62	0.55	0.207
MG	0.85	0.83	0.87	0.79	0.071
P	11.42	11.52	11.76	11.48	0.349
FE	0.44	0.41	0.39	0.37	0.087
			mg/kg++		
AL	2.81	2.88	4.85	3.13e	1.653
ZN	76.62b	82.68	90.35	91.78	7.738
MN	4.87	4.56	4.88	5.61	1.149
B	0.96b	0.50	0.41	<0.18	-----
CU	15.83b	13.48	14.90	13.51e	1.174
PB	1.36	1.13	1.40	<1.17	-----
CR	<0.36	0.33	0.40	0.51	-----
NI	0.89	0.62	1.12	<0.54	-----
CD	3.09b	10.85	24.75	22.41c	8.096

\+ STANDARD DEVIATION
++ 70 C WEIGHT BASIS
a CONTROL VS ALL SLUDGE LEVELS (P<0.05)
b CONTROL VS ALL SLUDGE LEVELS (P<0.01)
c LINEAR EFFECT WITHIN SLUDGE LEVELS (P<0.05)
d LINEAR EFFECT WITHIN SLUDGE LEVELS (P<0.01)
e QUADRATIC EFFECT WITHIN SLUDGE LEVELS (P<0.05)
f QUADRATIC EFFECT WITHIN SLUDGE LEVELS (P<0.01)

TABLE 11. ELEMENTAL CONTENT OF HEART COLLECTED FROM FEMALE GOATS FED CORN SILAGE GROWN ON SLUDGE-AMENDED SOILS (FOLLOWING 3 YEARS OF FEEDING).

ITEM	TREATMENT CONTROL	LOW	MEDIUM	HIGH	S+
NO. OF GOATS	7	4	6	9	
ELEMENT			g/kg++		
NA	4.01	3.80	4.48	3.97	0.831
K	10.90	9.91	10.27	10.57	1.095
CA	0.17	0.16	0.18	0.17	0.032
MG	0.90	0.84	0.86	0.87	0.119
P	8.40	7.96	8.13	8.54	0.503
FE	0.20	0.22	0.23	0.25	0.081
			ug/kg++		
AL	1.35	<0.98	1.47	1.08	-----
ZN	72.58	70.60	70.58	73.99	6.470
MN	1.10	0.89	1.18	2.01	1.471
B	<0.47	<0.23	0.63	<0.45	-----
CU	16.90	16.53	17.78	19.32	4.326
PB	<0.64	<0.53	<0.62	<0.74	-----
CR	<0.44	<0.47	0.52	<0.54	-----
NI	0.82	<0.61	0.93	1.00	-----
CD	<0.08	0.10	<0.06	0.07	-----

+ STANDARD DEVIATION
++ 70 C WEIGHT BASIS
a CONTROL VS ALL SLUDGE LEVELS (P<0.05)
b CONTROL VS ALL SLUDGE LEVELS (P<0.01)
c LINEAR EFFECT WITHIN SLUDGE LEVELS (P<0.05)
d LINEAR EFFECT WITHIN SLUDGE LEVELS (P<0.01)
e QUADRATIC EFFECT WITHIN SLUDGE LEVELS (P<0.05)
f QUADRATIC EFFECT WITHIN SLUDGE LEVELS (P<0.01)

TABLE 12. ELEMENTAL CONTENT OF MUSCLE COLLECTED FROM FEMALE GOATS FED CORN SILAGE GROWN ON SLUDGE-AMENDED SOILS (FOLLOWING 3 YEARS OF FEEDING).

ITEM	TREATMENT CONTROL	LOW	MEDIUM	HIGH	S+
NO. OF GOATS	7	4	6	9	
ELEMENT			g/kg++		
NA	2.00	2.33	1.98	2.11	0.388
K	12.70	12.07	13.03	13.27c	0.764
CA	0.17a	0.15	0.14	0.15	0.020
MG	0.90	0.90	0.86	0.91	0.045
P	7.09	7.30	6.93	7.19	0.454
FE	0.12	0.13	0.12	0.11	0.022
			ug/kg++		
AL	1.94a	1.23	<0.83	1.78	-----
ZN	201.40	162.58	207.72	203.06c	0.003
MN	0.67	0.59	0.70	0.59	0.144
B	<0.63	<0.21	0.51	0.47	-----
CU	4.50	6.08	3.53	4.23	2.523
PB	<0.60	<0.60	<0.65	<0.64	-----
CR	<0.34	<0.38	0.32	0.47	-----
NI	0.59	0.73	<0.72	<0.79	-----
CD	<0.06	<0.05	<0.07	<0.12	-----

+ STANDARD DEVIATION
++ 70 C WEIGHT BASIS
a CONTROL VS ALL SLUDGE LEVELS (P<0.05)
b CONTROL VS ALL SLUDGE LEVELS (P<0.01)
c LINEAR EFFECT WITHIN SLUDGE LEVELS (P<0.05)
d LINEAR EFFECT WITHIN SLUDGE LEVELS (P<0.01)
e QUADRATIC EFFECT WITHIN SLUDGE LEVELS (P<0.05)
f QUADRATIC EFFECT WITHIN SLUDGE LEVELS (P<0.01)

1957). Powell et al. (1964) reported that cattle fed 0.32 mg Cd/kg of ration had liver and kidney concentrations of Cd of 4.00 and <2.00 mg/kg, respectively. In contrast, adult beef cows ingesting forage irrigated with sludge for four years accumulated Cd levels of 40.7 and 7.1 mg/kg in the kidney and liver, respectively (Fitzgerald, 1980). These values are twice as high as the values observed in this study for comparable tissues.

Cadmium levels in heart and muscle were minimal and averaged 0.08 and 0.07 mg/kg, respectively.

Zinc concentrations in liver from animals on control, low, medium, and high treatments were 90.3, 91.2, 85.9, and 88.8 mg/kg, respectively; these values did not differ significantly among treatments ($P > 0.05$). Kidney Zn ranged from 76.6 (control) to 91.8 mg/kg (high) with control animals having less ($P < 0.01$) Zn than animals fed sludge fertilized corn silage. Heart tissue averaged 71.9 mg Zn/kg and did not differ significantly among treatments. This lack of Zn accumulation in the heart was also noted by Fitzgerald (1980) for adult cows ingesting forages irrigated with sludge over a four year period. Muscle from control animals contained 201 mg Zn/kg, while animals fed sludge fertilized silage had a linear ($P < 0.05$) increase of muscle Zn from 163 mg/kg on the low treatment to an average concentration of 205 mg/kg on the medium and high treatments. The reduced muscle Zn for animals of the low treatment is unknown, but may be associated with other factors that lowered the productive capacity of goats in this treatment. Anke et al. (1973, as cited by Haenlein, 1980) observed Zn contents of goat liver, kidney, heart, and muscle as 177, 122, 85, 199 mg/kg, respectively.

Copper concentrations in livers and kidneys were significantly ($P < 0.01$) lower, approximately 2 mg/kg, from animals of the sludge fertilized corn silage treatments, than from animals fed control silage. Goat liver and kidney contents of Cu observed by Anke et al. (1973, as cited by Haenlein, 1980) averaged 8.9 and 11.2 mg/kg, respectively, and are lower than the values observed in this study (Tables 9 and 10). Copper contents of liver tended to decrease as amount of Cd in liver increased and may have resulted from the antagonistic blocking of the protein necessary for Cu absorption (Hennig et al., 1974). Heart and muscle contents of Cu averaged 17.6 and 4.6 mg/kg, respectively, and were similar to those observed by Anke et al. (1973, as cited by Haenlein, 1980).

Lead contents of livers averaged <0.7 mg/kg. Average values for Pb contents of kidney, heart, and muscle were 1.3, <0.6, and <0.6 mg/kg, respectively. Fick et al. (1976) found that sheep livers contained 1.3 mg Pb/kg DM. Limited data are available concerning Pb content of other tissues. Liver contained <0.33 mg Cr/kg, while kidney, heart, and muscle averaged <0.5 mg Cr/kg. No significant differences ($P > 0.05$) in tissue Cr concentrations

were observed among treatments.

Nickel contents of goat liver were 1.0 mg/kg DM; tissue concentrations of less than 1 ppm fresh weight have been observed (Whanger, 1973; O'Dell et al., 1971; Schroeder et al., 1963, 1964, 1974). Nickel contents of kidney ranged from 0.5 (high) to 1.1 mg/kg (medium); and there were no significant differences among treatments. Heart Ni ranged from 0.6 (low) to 1.0 mg/kg (high) and tended to increase as amount of sludge applied increased. Goat muscle ranged from 0.6 (control) to <0.8 mg Ni/kg (high), and animals fed sludge fertilized silage diets tended to have more Ni in muscle tissue than control animals. Dietary Ni is poorly absorbed, probably in the range of 1 to 10%, even at high Ni intakes (Underwood, 1977). Most absorbed Ni is excreted in feces, with smaller amounts excreted in urine and sweat.

Liver and kidney Mn concentrations averaged 6.3 and 5.0 mg/kg, respectively, and were not affected by treatment ($P > 0.05$). Heart Mn values ranged from 0.9 (low) to 2.0 mg/kg (high) with a tendency for Mn to increase as amount of sludge applied as fertilizer increased. Muscle Mn averaged 0.64 mg/kg and was not significantly different among treatments. Manganese contents of liver, kidney, heart, and muscle were 9.9, 4.2, 1.9, and 1.6 mg/kg, respectively, for mature female goats on a normal diet (Anke et al., 1973, as cited by Haenlein, 1980).

Average B contents of animal tissues were: liver, 0.60 mg/kg; kidney, 0.51 mg/kg; heart, 0.45 mg/kg; and muscle, 0.45 mg/kg. Soft tissue contents of B lie between 0.5 and 1.5 mg/kg dry weight (Alexander et al., 1951; Forbes et al., 1954; Hamilton et al., 1972/1973; Hove, 1939). Treatment did not significantly ($P > 0.05$) affect tissue concentrations of Al, Ca, Fe, K, Mg, Na, and P (Tables 9, 10, 11, and 12).

LAMB FEEDING TRIALS

Performance

Although significant ($P < 0.05$) only in year II, lambs fed sludge fertilized corn silage tended to have higher daily gains than lambs fed control silage (Table 13). It is possible that some elements in corn silage, that were supplied by sewage sludge, resulted in the improved performance. Daily gains averaged 0.19 kg/day for lambs fed sludge fertilized silage and were similar to gains reported by Jordan et al. (1971) for lambs on corn silage ration. Heffron et al. (1980) observed that lambs fed corn silage grown on sludge amended soil had a lower rate of gain than lambs fed control corn silage; however, their reported rate of gain was only one-half that observed in this study, even for control animals.

Daily feed intakes (kg dry matter) of lambs are shown in

TABLE 13. PERFORMANCE DATA OF LAMBS FED CORN SILAGE GROWN ON SLUDGE-AMENDED SOILS.

	YEAR I					YEAR II					YEAR III				
	TREATMENT					TREATMENT					TREATMENT				
ITEM	CONTROL	LOW	MEDIUM	HIGH	S+	CONTROL	LOW	MEDIUM	HIGH	S	CONTROL	LOW	MEDIUM	HIGH	S
NO. OF LAMBS	8	8	8	8		8	8	8	8		8	7	8	7	
ANIMAL WEIGHTS															
INITIAL WEIGHT (KG)	20.1	20.5	21.6	21.5	2.45	24.1	21.4	23.2	21.8	.67	25.6	24.9	25.9	28.2	4.22
DAILY GAIN (KG)	0.18	0.20	0.20	0.20	0.03	0.14a	0.18	0.17	0.17	.03	0.19	0.21	0.21	0.20	0.05
AVERAGE DAILY FEED (KG DRY MATTER)															
CORN SILAGE	0.94a	0.88	0.73	0.80	0.02	1.20	1.46	1.42	1.14	.04	0.90	0.95	1.06	0.91	0.25
SOYBEAN MEAL	0.22	0.23	0.23	0.23	---	0.23	0.23	0.23	0.23	---	0.23	0.23	0.23	0.23	---
TOTAL	1.17b	1.11	0.96	1.03df	0.03	1.43b	1.69	1.65	1.37df	.08	1.13	1.18	1.29	1.14	0.19
FEED EFFICIENCY (KG GAIN/ KG INTAKE)	0.15b	0.18	0.21	0.19	0.03	0.10	0.11	0.10	0.12	.02	0.18	0.18	0.16	0.18	0.06

+ STANDARD DEVIATION
a CONTROL VS ALL SLUDGE LEVEL (P<0.05)
b CONTROL VS ALL SLUDGE LEVEL (P<0.01)

Table 13, and were not significantly affected by treatment in any of the three years ($P > 0.05$). Huntington et al. (1981) reported similar feed intakes for lambs fed rations containing concentrate, while Jordan et al. (1971) found average feed intakes of lambs fed corn silage to be 1.18 kg/day. Feed efficiencies of lambs fed sludge fertilized corn silage were higher ($P < 0.01$) than for lambs fed control corn silage only in year I, where control lambs consumed slightly more feed and gained slower than lambs fed sludge-fertilized corn silage. Feed efficiency averaged 0.11 lower during year II, than the average 0.18 efficiency noted for years I and III, but considerably higher than the 0.05 kg gain/kg feed intake efficiency reported by Heffron et al. (1980).

Blood Composition

Elemental analyses of blood dry matter are presented in Table 14. Cadmium, Ca, Cu, Fe, Mg, Mn, Ni, P, Pb, and Zn concentrations of blood were not consistently affected by treatment.

Lambs fed corn silage from control, low, medium, and high sludge treatments had blood Al levels of 7.7, 2.0, 1.6, and 0.1 mg/kg DM (year I); 3.2, 3.1, 2.8, and 2.7 mg/kg DM (year II); 2.4, 3.0, 1.8, and 0.9 mg/kg (year III), respectively. In each year, there was a tendency for blood Al to decrease as amount of sludge applied as fertilizer increased.

Cadmium contents of blood dry matter (<0.05 mg/kg) did not differ significantly ($P < 0.05$) in any of the three years, even though liver and kidney Cd concentrations were increased by the use of sewage sludge as a fertilizer. Dorn (1973) has reported a range of 3.8 to 21.6 µg Cd/L in cattle blood, while Fitzgerald (1980) noted blood Cd levels of 0.002 to 30.007 mg/kg (wet weight basis) in adult cows. In the latter case, accumulation of Cd in the blood did not occur even though the animals had ingested forage irrigated with sewage sludge for four years.

Organ Composition

The elemental concentrations in tissues collected from lambs are presented in Tables 15, 16, 17, and 18. Cadmium contents of liver from animals fed control, low, medium, and high silage were 0.6, 0.8, 1.1, 1.3 mg/kg, year I; 0.3, 2.0, 2.6, 5.3 mg/kg year II; and 0.5, 1.1, 2.5, 3.6 mg/kg, year III, respectively. In each year, livers from control animals had less ($P < 0.05$, year I; $P < 0.01$, years II and III) Cd than livers from animals fed sludge fertilized corn silage. Also, there was a linear increase in the amount of Cd in liver as the amount of sludge applied increased. These values are considerably lower than the 5.8 mg Cd/kg of liver reported by Heffron et al. (1980) for lambs consuming corn silage containing 1.7 mg Cd/kg for a 274 day feeding period. Even though this study (TS) versus the Heffron et al. (1980) (HS)

TABLE 14. ELEMENTAL CONTENT OF BLOOD COLLECTED FROM LAMBS FED CORN SILAGE GROWN ON SLUDGE-AMENDED SOILS.

	YEAR I					YEAR II					YEAR III				
	TREATMENT					TREATMENT					TREATMENT				
ITEM	CONTROL	LOW	MEDIUM	HIGH	S+	CONTROL	LOW	MEDIUM	HIGH	S	CONTROL	LOW	MEDIUM	HIGH	S
NO. OF LAMBS	8	8	8	8		8	8	8	8		8	7	8	7	
ELEMENT	g/kg++					g/kg					g/kg				
NA	12.52b	13.81	13.97	13.90	0.959	13.74b	15.15	14.94	14.40	1.070	14.24	14.26	15.28	13.82	1.645
K	1.86	2.04	1.90	1.94	0.226	2.71	1.49	1.65	2.02	1.486	3.49	3.16	2.46	2.51	1.902
CA	0.32	0.31	0.29	0.30	0.033	0.31b	0.37	0.40	0.33e	0.056	0.35	0.33	0.36	0.33e	0.035
MG	0.14	0.15	0.15	0.14	0.021	0.17	0.17	0.19	0.17	0.026	0.15	0.13	0.16	0.14f	0.020
P	0.96b	1.09	1.06	1.10	0.084	1.23	1.19	1.19	1.16	0.092	1.12	1.12	1.10	1.04	0.082
FE	2.24	2.24	2.27	2.38	0.192	1.93	1.93	2.11	2.14	0.179	1.92	1.86	1.95	2.02	0.269
	ug/kg++					ug/kg					ug/kg				
AL	7.66	2.01	<1.58	<0.10	-----	3.24	3.10	2.76	2.70c	1.416	2.35	2.95	1.76	<0.88	-----
ZN	20.15	19.26	20.98	20.54	2.817	16.08	15.90	17.88	16.78	1.758	15.38	14.83	14.51	15.44	3.006
MN	<0.14	<0.10	<0.10	<0.10	-----	<0.13	<0.15	<0.36	<0.12	-----	<0.11	<0.13	<0.10	<0.10	-----
B	<0.52	<0.14	<2.01	4.42	-----	3.25b	2.75	3.10	2.53e	0.484	3.41b	2.44	1.98	1.45	1.083
CU	4.75	4.61	4.78	3.93	0.676	5.24	5.56	5.00	4.86	0.732	3.26	2.97	3.18	2.87	0.046
PB	<1.00	<1.00	<1.00	<1.00	-----	<1.00	<1.00	<1.00	<1.00	-----	<1.00	<1.00	<1.00	<1.00	-----
CR	0.25	0.32	<0.10	<0.10	-----	0.27	0.27	0.33	0.37d	0.063	<0.10	0.74	<0.16	<0.13	-----
NI	<0.30	<0.34	<0.30	<0.30	-----	0.51	0.52	0.56	0.49	0.138	0.41	0.53	<0.30	<0.30	-----
CD	0.044	0.034	0.054	0.034	0.038	0.013	0.029	0.019	0.019	0.017	0.010	0.012	0.010	0.010	0.009
AS	<0.02	<0.02	<0.02	<0.02	-----	<0.02	<0.02	<0.02	<0.02	-----	<0.02	<0.02	<0.02	<0.02	-----
SE	0.28	0.27	0.30	0.36	-----	0.39	0.31	0.31	0.28	-----	0.27	0.29	0.23	0.24	-----
HG	----	----	----	----	-----	<0.03	<0.10	<0.07	<0.05	-----	<0.04	<0.08	<0.03	<0.02	-----

\+ STANDARD DEVIATION
++ 70 C WEIGHT BASIS
a CONTROL VS ALL SLUDGE LEVELS (P<0.05)
b CONTROL VS ALL SLUDGE LEVELS (P<0.01)
c LINEAR EFFECT WITHIN SLUDGE LEVELS (P<0.05)
d LINEAR EFFECT WITHIN SLUDGE LEVELS (P<0.01)
e QUADRATIC EFFECT WITHIN SLUDGE LEVELS (P<0.05)
f QUADRATIC EFFECT WITHIN SLUDGE LEVELS (P<0.01)

TABLE 15. ELEMENTAL CONTENT OF LIVER COLLECTED FROM LAMBS FED CORN SILAGE GROWN ON SLUDGE-AMENDED SOILS.

	YEAR I					YEAR II					YEAR III				
	TREATMENT					TREATMENT					TREATMENT				
ITEM	CONTROL	LOW	MEDIUM	HIGH	S+	CONTROL	LOW	MEDIUM	HIGH	S	CONTROL	LOW	MEDIUM	HIGH	S
NO. OF LAMBS	8	8	8	8		8	8	8	8		8	7	8	7	
ELEMENT	g/kg++					g/kg					g/kg				
NA	2.24	2.33	2.20	2.08	0.289	1.93	1.88	1.94	1.81	0.183	2.21	2.06	2.27	2.20	0.206
K	8.78	9.14	9.10	8.83	0.326	8.34	8.49	8.40	8.23	0.777	9.29a	9.79	9.82	9.49	0.477
CA	0.22	0.22	0.21	0.22	0.020	0.17	0.16	0.15	0.15	0.019	0.17	0.17	0.17	0.17	0.013
MG	0.52	0.58	0.57	0.49e	0.062	0.38	0.43	0.40	0.37	0.100	0.42	0.48	0.52	0.47	0.082
P	11.95	12.00	11.49	11.29d	0.414	9.90	10.52	10.24	10.28	0.851	11.20a	11.61	12.12	11.37e	0.538
FE	0.33	0.32	0.25	0.25	0.072	0.36b	0.18	0.18	0.19	0.061	0.22	0.19	0.23	0.25	0.062
	ug/kg++					ug/kg					ug/kg				
AL	2.22	2.00	2.35	1.77	1.172	2.79	2.78	2.25	3.08	0.900	1.69a	2.46	2.74	1.81	0.673
ZN	102.21	110.06	103.56	97.58	14.196	79.09	89.16	85.35	83.65	21.129	105.28	105.90	117.74	114.43	15.483
MN	9.84	10.44	12.21	11.03	2.691	5.33	7.07	6.34	4.74c	1.681	8.10	8.38	8.41	9.07	1.661
B	0.26	0.19	0.38	0.25	0.241	0.88	0.66	0.88	1.13c	0.399	0.44	0.46	0.56	0.47	0.185
CU	185.24	196.49	215.40	209.50	111.569	53.25	63.73	89.25	65.63	30.421	164.34	163.76	168.13	127.93	54.147
PB	0.96	0.84	<0.93	<1.18	-----	1.59	1.69	1.50	1.49	0.591	<1.00	<0.70	<0.90	<0.70	-----
CR	0.64b	0.70	0.70	0.70	0.049	<0.30	<0.28	<0.26	<0.20	-----	<0.40	<0.40	<0.40	<0.40	-----
NI	0.24	<0.16	<0.19	<0.15	-----	<0.38	<0.35	<0.34	<0.33	-----	<0.34	<0.37	<0.34	<0.34	-----
CD	0.56a	0.82	1.06	1.31	0.527	0.29b	1.97	3.56	5.29d	1.320	0.52b	1.13	2.52	3.58d	1.287
AS											-----	-----	-----	<0.02	-----
SE											1.25	1.18	1.22	1.37	-----
HG											<0.04	0.05	<0.06	<0.07	-----

\+ STANDARD DEVIATION
++ 70 C WEIGHT BASIS
a CONTROL VS ALL SLUDGE LEVELS (P<0.05)
b CONTROL VS ALL SLUDGE LEVELS (P<0.01)
c LINEAR EFFECT WITHIN SLUDGE LEVELS (P<0.05)
d LINEAR EFFECT WITHIN SLUDGE LEVELS (P<0.01)
e QUADRATIC EFFECT WITHIN SLUDGE LEVELS (P<0.05)
f QUADRATIC EFFECT WITHIN SLUDGE LEVELS (P<0.01)

TABLE 16. ELEMENTAL CONTENT OF KIDNEY COLLECTED FROM LAMBS FED CORN SILAGE GROWN ON SLUDGE-AMENDED SOILS.

	YEAR I					YEAR II					YEAR III				
	TREATMENT					TREATMENT					TREATMENT				
ITEM	CONTROL	LOW	MEDIUM	HIGH	S+	CONTROL	LOW	MEDIUM	HIGH	S	CONTROL	LOW	MEDIUM	HIGH	S
NO. OF LAMBS	8	8	8	8		8	8	8	8		8	7	8	7	
ELEMENT	g/kg++					g/kg					g/kg				
NA	5.57	5.78	5.46	5.95e	0.431	8.02a	7.45	7.70	7.75	0.593	8.14	7.55	8.23	8.09	0.644
K	11.26	11.44	10.93	11.40	0.723	12.39	12.58	13.01	12.80	0.929	13.51	13.00	13.29	13.68e	0.593
CA	0.66	0.93	0.79	0.88	0.295	1.48	0.65	0.56	1.38	1.222	0.36	0.33	0.37	0.36	0.049
MG	0.84	0.88	0.86	0.87	0.005	1.08	0.93	0.97	0.96	0.098	0.96b	0.89	0.92	0.94	0.038
P	11.89	12.22	11.62	12.30e	0.722	13.37	13.06	13.24	13.13	0.683	14.09a	13.16	13.63	13.70	0.520
FE	0.22	0.19	0.21	0.20	0.036	0.45b	0.25	0.24	0.27	0.109	0.29a	0.18	0.19	0.23	0.090
	ug/kg++					ug/kg					ug/kg				
AL	4.75	3.26	4.34	2.49	1.693	7.11b	4.44	3.88	4.25	1.048	5.09	4.52	4.82	5.90c	1.027
ZN	108.82	103.34	109.34	112.96	13.754	103.09b	109.78	123.67	126.50d	6.748	99.71a	103.30	111.23	112.85	10.739
MN	5.57	5.77	5.71	5.88	1.083	3.28	3.87	3.51	3.75	0.711	6.17	6.15	5.53	6.02	0.647
B	0.96	1.29	0.94	1.13	0.458	1.83b	1.37	1.47	1.39	0.278	1.14	1.18	1.09	1.25	0.150
CU	15.30	16.89	15.35	16.76	2.313	15.96b	16.94	17.79	17.85	12.048	19.43	20.47	19.49	19.57	1.656
PB	1.28	1.45	1.34	1.46	0.687	2.78	2.49	2.27	2.15	0.890	2.00	1.20	1.80	2.20d	0.410
CR	0.87	0.82	0.84	0.80	0.060	<0.21	<0.58	<0.20	<0.38	-----	<0.40	<0.40	<0.40	<0.40	-----
NI	<0.23	<0.21	<0.17	<0.16	-----	<0.38	<0.58	<0.34	<0.38	-----	0.72	0.59	<0.73	0.57	-----
CD	1.57	1.38	1.90	3.11d	0.972	2.09b	5.07	10.89	18.94d	4.030	0.78b	2.70	7.31	10.18d	3.724
AS											0.03	<0.03	<0.03	0.04	-----
SE											3.66	3.56	3.51	3.85	-----
HG											<0.06	<0.12	0.14	0.12	-----

\+ STANDARD DEVIATION
++ 70 C WEIGHT BASIS
a CONTROL VS ALL SLUDGE LEVELS (P<0.05)
b CONTROL VS ALL SLUDGE LEVELS (P<0.01)
c LINEAR EFFECT WITHIN SLUDGE LEVELS (P<0.05)
d LINEAR EFFECT WITHIN SLUDGE LEVELS (P<0.01)
e QUADRATIC EFFECT WITHIN SLUDGE LEVELS (P<0.05)
F QUADRATIC EFFECT WITHIN SLUDGE LEVELS (P<0.01)

TABLE 17. ELEMENTAL CONTENT OF HEART COLLECTED FROM LAMBS FED CORN SILAGE GROWN ON SLUDGE-AMENDED SOILS.

	YEAR I					YEAR II					YEAR III				
	TREATMENT					TREATMENT					TREATMENT				
ITEM	CONTROL	LOW	MEDIUM	HIGH	S+	CONTROL	LOW	MEDIUM	HIGH	S	CONTROL	LOW	MEDIUM	HIGH	S
NO. OF LAMBS	8	8	8	8		8	8	8	8		8	7	8	7	
ELEMENT	g/kg++					g/kg					g/kg				
NA	3.48b	3.97	4.16	4.48	0.482	4.45	4.45	4.59	4.48	0.354	4.80	4.75	4.99	4.77	0.269
K	9.42b	10.54	11.74	10.80	1.199	12.45	11.89	11.72	12.21	0.788	13.49	13.58	13.66	13.64	0.620
CA	0.23	0.24	0.19	0.22cf	0.026	0.24	0.24	0.24	0.23	0.041	0.22	0.22	0.23	0.22	0.017
MG	0.82	0.86	0.93	0.88	0.106	1.06	1.01	1.00	1.02	0.006	1.08	1.08	1.06	1.03	0.047
P	8.28a	8.87	9.85	9.44	1.094	9.53	9.39	9.40	9.54	0.285	10.16	10.11	10.01	9.85	0.362
FE	0.19	0.18	0.19	0.19	0.022	0.22	0.21	0.21	0.21	0.021	0.21	0.22	0.22	0.23	0.020
	ug/kg++					ug/kg					ug/kg				
AL	3.31	3.68	3.28	3.28	1.205	3.97a	3.03	3.13	3.07	0.885	2.65	3.75	1.95	1.77c	1.606
ZN	64.12	65.72	70.10	72.10	7.527	82.05	82.53	78.58	81.82	4.029	75.85	75.04	74.18	69.91	5.531
MN	1.35	1.30	1.51	1.51	0.304	1.16	1.42	1.47	1.20	0.245	1.30	1.40	1.30	1.33	0.162
B	0.30b	0.86	1.11	0.91	0.476	0.46	0.83	1.06	0.94	0.276	<0.63	0.65	<0.35	<0.32	-----
CU	12.99	13.61	14.49	14.84	2.051	16.27	16.63	17.25	16.05	1.271	19.28b	18.29	16.65	17.63f	0.983
PB	<0.70	<0.70	<0.70	<0.70	-----	<0.50	<0.50	<0.50	<0.50	-----	<0.50	<0.70	<0.50	<0.60	-----
CR	0.49	0.50	0.42	0.40c	0.084	0.30	0.36	<0.31	0.51	-----	<0.40	<0.40	<0.40	<0.40	-----
NI	<0.15	<0.21	0.28	0.36	-----	<0.38	<0.36	<0.35	<0.35	-----	1.28	<0.92	1.51	0.88	-----
CD	<0.10	<0.10	<0.10	<0.08	-----	<0.10	<0.11	<0.13	<0.15	-----	<0.10	<0.08	<0.08	0.10	-----
AS											<0.03	<0.03	<0.03	0.04	-----
SE											0.88	0.82	0.88	0.81	-----
HG											<0.03	0.15	<0.04	<0.02	-----

\+ STANDARD DEVIATION
++ 70 C WEIGHT BASIS
a CONTROL VS ALL SLUDGE LEVELS (P<0.05)
b CONTROL VS ALL SLUDGE LEVELS (P<0.01)
c LINEAR EFFECT WITHIN SLUDGE LEVELS (P<0.05)
d LINEAR EFFECT WITHIN SLUDGE LEVELS (P<0.01)
e QUADRATIC EFFECT WITHIN SLUDGE LEVELS (P<0.05)
f QUADRATIC EFFECT WITHIN SLUDGE LEVELS (P<0.01)

TABLE 18. ELEMENTAL CONTENT OF MUSCLE COLLECTED FROM LAMBS FED CORN SILAGE GROWN ON SLUDGE-AMENDED SOILS.

	YEAR II					YEAR III				
	TREATMENT					TREATMENT				
ITEM	CONTROL	LOW	MEDIUM	HIGH	S+	CONTROL	LOW	MEDIUM	HIGH	S
NO. OF LAMB	8	8	8	8		8	7	8	7	
ELEMENT	g/kg++					g/kg				
NA	3.16	3.72	3.45	3.37	0.462	3.10	2.92	2.94	2.91	0.377
K	12.60	12.18	11.82	12.21	1.396	15.04	15.40	15.04	14.49	0.898
CA	0.21	0.24	0.22	0.23	0.029	0.20	0.20	0.19	0.18	0.028
MG	0.92	0.92	0.89	0.96	0.076	1.06	1.08	1.04	0.99d	0.055
P	6.75	6.60	6.40	6.57	0.627	8.22	8.37	8.10	7.90	0.428
FE	0.078a	0.069	0.065	0.072	0.014	0.057	0.060	0.058	0.059	0.006
	ug/kg++					ug/kg				
AL	4.44	3.80	3.93	4.91	1.444	3.33	3.09	1.96	1.93	1.624
ZN	246.63	257.13	254.71	254.50	29.831	174.31	171.06	178.01	171.79	18.534
MN	0.57a	0.43	0.40	0.54	0.144	0.35	0.34	0.31	0.43	0.103
B	0.56	0.61	0.31	0.53e	0.193	<0.19	<0.13	<0.07	<0.08	-----
CU	5.20	5.78	7.77	7.28	2.027	5.29a	4.38	4.81	5.03c	0.600
PB	<0.51	<0.53	<0.50	<0.51	-----	<0.80	<0.60	<0.60	<0.70	-----
CR	0.51	0.51	0.53	<0.45	-----	<0.40	<0.40	<0.40	<0.40	-----
NI	<0.58	<0.46	<0.58	<0.65	-----	<0.77	<1.32	<0.93	<1.60	-----
CD	<0.12	<0.10	<0.10	<0.13	-----	<0.06	<0.06	<0.11	<0.06	-----
AS						0.04	0.05	0.04	0.04	-----
SE						0.41	0.36	0.36	0.39	-----
HG						<0.03	<0.03	<0.03	<0.03	-----

\+ STANDARD DEVIATION
++ 70 C WEIGHT BASIS
a CONTROL VS ALL SLUDGE LEVELS (P<0.05)
b CONTROL VS ALL SLUDGE LEVELS (P<0.01)
c LINEAR EFFECT WITHIN SLUDGE LEVELS (P<0.05)
d LINEAR EFFECT WITHIN SLUDGE LEVELS (P<0.01)
e QUADRATIC EFFECT WITHIN SLUDGE LEVELS (P<0.05)
f QUADRATIC EFFECT WITHIN SLUDGE LEVELS (P<0.01)

are similar, the following conditions must be considered before making direct comparisons:

1) different breeds of lambs were used;

2) length of feeding trials differed, 100 days in each of three years (TS) vs. 274 days in one year (HS);

3) in this study, only two treatments had silage Cd concentrations equal to that used in the Heffron et al. (1980) study, high year I and low, year II;

4) animal performance (rate of gain and feed efficiency) in the studies by Heffron et al. (1980) was only one-half of that observed in this study.

Doyle and Pfander (1975) reported an average Cd concentration of dry sheep liver of 1.69 mg/kg. In contrast, Kienholz et al. (1974) reported an average liver Cd concentration for sheep of 0.09 mg/kg and Mills and Dalgarno (1972) reported an average Cd concentration of lamb liver in the U.K. as 0.14 mg/kg DM.

Kidney Cd contents from animals fed control, low, medium, and high silages were 1.6, 1.4, 1.9, 3.1 mg/kg, year I; 2.1, 5.1, 10.9, 18.9 mg/kg, year II; and 0.8, 2.7, 7.3, 10.2 mg/kg, year III. In each year, control lambs had lower kidney Cd concentrations than those fed sludge fertilized corn silage ($P < 0.01$ in years II and III). Also, in each year there was a linear ($P < 0.01$) increase in kidney Cd as amount of sludge applied increased. Reported kidney Cd concentrations of lambs fed normal diets include: 1.93 mg/kg DM (Lee and Jones, 1976), 1.06 mg/kg of wet weight (Stabel-Taucher et al., 1975), 4.42 mg/kg DM (Doyle and Pfander, 1975), and 4.30 mg/kg of wet weight (Wright et al., 1977). The only time the kidney Cd level in this study reached the value (18.5 mg Cd/kg) reported by Heffron et al. (1980) was for the high treatment, year II, (18.9 mg Cd/kg) when lambs were consuming a silage ration containing 2.5 times the Cd concentration.

Cadmium concentrations in heart and muscle were low and not affected by treatments. Cadmium accumulates in the body over time because there is no homeostatic mechanism to regulate body concentrations (Miller, 1971). When fed in small amounts, Cd inhibits essential metabolic functions of Zn, Cu, and Fe in some species (Flick et al., 1971; Task Group, 1973). Due to its relatively high concentration in kidneys and high concentration in the protein methallothionein, it is possible there is a biological need for Cd in the diet (Gunn and Gould, 1957; Underwood, 1971; Doyle and Pfander et al., 1974). However, a greater concern is the possible toxic effects of Cd on humans and animals (Meek, 1959; Schroeder and Vinton, 1962; Perry and Erlanger, 1974).

Zinc, the only other metal to accumulate in corn silage as a

result of sludge fertilization, was not significantly affected by treatment and averaged 99, 71, and 213 mg/kg DM, respectively, in liver, heart, and muscle. Zinc concentrations of 83 to 193 mg/kg DM in muscle and of 106 to 136 mg/kg DM in lamb liver have been reported (Standish and Ammerman, 1971; Watson et al., 1973; Doyle and Pfander, 1975; Fick et al., 1976), and are of the same order of magnitude found in this study.

Contents of Zn in kidneys from animals fed corn silages from control, low, medium, and high treatments were 109, 103, 109, and 113 mg/kg DM in year I; 103, 110, 124, and 127 mg/kg DM in year II; and 100, 103, 111, and 113 mg/kg DM in year III. Kidneys from control animals tended to contain less Zn than those from animals fed sludge fertilized corn silage. The lack of a major dose-related increase in kidney Zn may be a result of high dietary Cu (trace mineral salt) and Cd (corn silage) interacting to reduce the absorption of Zn (Chaney, 1980). Miller (1969) stated that homeostatic mechanisms are generally adequate to eliminate excess amounts of Zn.

Zinc concentrations reported in kidney were similar to those observed by Doyle and Pfander (1975), Fick et al. (1976), Watson et al. (1973), and Standish and Ammerman (1971). They also agree closely with values reported for beef cattle consuming forages fertilized with sewage sludge (Bertrand et al., 1980; Fitzgerald, 1980). But, these data (this study plus cited literature) are all one to two orders of magnitude less than kidney Zn levels reported by Heffron et al. (1980) for lambs fed sludge fertilized corn silage. Although direct comparison of their data with this study must be tempered for the reasons listed in a previous section, the differences between kidney Zn concentrations observed in the two studies remain unexplained.

Copper concentrations in livers were not significantly affected by treatments ($P > 0.05$). Liver Cu concentrations were low for all lambs, particularly in year II. Kidney Cu of lambs fed control, low, medium, and high corn silages were 15.3, 16.9, 15.4, and 16.8 mg/kg DM (year I); 16.0, 17.0, 17.8, and 18.0 mg/kg DM (year II); 19.4, 20.5, 19.5, and 19.6 mg/kg DM (year III). Although significant ($P < 0.05$) only in year II, kidneys from control lambs contained less Cu than those from lambs fed sludge fertilized corn silage. In all three years, kidney Cu levels were above the reported range of 9 to 15 ppm (Underwood, 1977). In year III, Cu contents of muscle from control lambs were higher ($P < 0.05$) than those fed sludge fertilized corn silage, but Cu contents of muscle increased ($P < 0.05$) with increasing amounts of sludge application. The same trend was observed in year II. This was not expected since muscle is less responsive than other tissues to dietary intakes of Cu (Hennig et al., 1974; Rucker et al., 1969, 1975).

Lead concentrations in liver, heart and muscle were not affected by treatment ($P > 0.05$) and were similar to those

reported by Fick et al. (1976). Lead in lamb kidneys averaged 1.4 (year I), 2.4 (year II), and 1.8 mg/kg (year III) and showed a linear increase ($P < 0.01$) with added sludge within sludge treatments during year III. Fick et al. (1976) reported lamb kidney Pb levels at 1.0 mg/kg and Buck and Osweler (1976) reported Pb contents on a wet weight basis of 0.72 mg/kg.

Elemental concentrations of Ca, Fe, K, Mg, Na, Ni, and P in liver, kidney, heart, and muscle were not significantly affected by treatment. Concentrations of Al, B, Fe, and Mn found in lamb liver, kidney, heart and muscle were within reported limits (Doyle and Pfander et al., 1974, 1975; Hamilton et al., 1972/1973; Standish and Ammerman, 1971; Watson et al., 1973; Fick et al., 1976) and were not consistently affected by treatment.

Feces Composition

Elemental content of feces collected from lambs fed sludge grown corn silage is presented in Table 19. In each year, Cd levels of feces from control lambs were significantly ($P < 0.01$) lower than Cd levels of feces from lambs fed sludge grown corn silage. Also, in each year there was a significant ($P < 0.01$) linear increase in Cd content of feces as the amount of sludge applied increased. These observations are consistent with the dietary Cd levels studied, the beef steer feeding results of Bertrand et al. (1980), and the fact that most ingested Cd passes directly into the feces (Ryan et al., 1982).

Histological Observation

In years II and III, liver and kidney tissues were studied histologically. Sections were examined microscopically at low power (40X) and high dry power (450X). There were no observable morphological differences among treatments for either tissue. In each year, liver lesions present were consistent with 1) moderate excess of mononuclear cells, including mature and immature lymphocytes and plasma cells, particularly at portal trials; and 2) moderate to severe excess of intracytoplasmic hepatocyte vacuoles, consistent morphologically with glycogen and associated with swelling of hepatocytes and compression of hepatic sinusoids. Kidney lesions were consistent with 1) mild to moderate numbers of calcified, intratubular microliths, especially at the renal capillary rip, and 2) moderate to severe proliferative glomerulopathy with associated filling of the potential renal sinus space within the glomerular capsule (glomerular swelling) and increase in size and numbers visceral epithelial and mesangial cells.

TABLE 19. ELEMENTAL CONTENT OF FECES COLLECTED FROM LAMBS FED CORN SILAGE GROWN ON SLUDGE-AMENDED SOILS.

	YEAR I					YEAR II					YEAR III				
	TREATMENT					TREATMENT					TREATMENT				
ITEM	CONTROL	LOW	MEDIUM	HIGH	S+	CONTROL	LOW	MEDIUM	HIGH	S	CONTROL	LOW	MEDIUM	HIGH	S
NO. OF LAMBS	8	8	8	8		8	8	8	8		8	7	8	7	
ELEMENT	g/kg++					g/kg					g/kg				
NA	6.64	6.61	4.86	3.80	1.506	1.62a	0.67	0.87	1.03	0.312	0.89	1.52	1.10	0.63c	0.246
K	4.82	4.61	6.45	4.89	1.733	9.74	10.94	10.88	11.07	0.915	11.13b	14.98	11.96	14.13F	0.379
CA	9.63	11.85	10.92	9.47	2.548	6.17a	4.33	4.66	5.28	0.562	5.50	5.53	5.64	6.66c	0.351
MG	2.59	3.50	2.46	3.67e	0.373	5.23a	3.69	3.69	3.83	0.561	5.86b	4.53	4.67	4.42	0.330
P	9.31	9.90	11.14	8.24	4.062	7.61a	5.12	5.35	5.79	0.925	7.86	8.42	7.00	7.96	0.670
FE	0.81	0.81	0.92	0.68	0.164	1.77	2.53	0.74	0.71	1.243	0.47b	0.44	0.56	0.92de	0.035
AL	0.47	0.47	0.61	0.37	0.156	0.14	0.11	0.16	0.12f	0.005	0.12	0.11	0.12	0.12e	0.003
ZN	0.46	0.51	0.55	0.42	0.082	0.27	0.19	0.23	0.26	0.037	0.15b	0.20	0.29	0.30de	0.013
	ug/kg++					ug/kg					ug/kg				
MN	495.00	524.00	543.50	397.50	82.679	128.65	82.15	81.40	97.05	11.536	111.60	87.75	87.70	107.60	10.897
B	6.16	5.93	5.55	5.26	0.935	6.20	5.56	6.05	5.94	0.594	6.96b	3.96	6.36	5.11dF	0.199
CU	51.87	53.43	60.86	37.54	13.090	12.68a	8.02	7.64	8.83	1.586	12.89	13.65	12.16	13.48	1.803
PB	3.10	2.40	2.50	2.40	-----	3.30a	1.85	1.65	1.80	0.415	2.50	1.90	2.60	3.10c	0.300
CR	3.95	4.20	4.80	3.05	0.981	1.70	0.95	1.85	1.45	0.306	1.55	1.20	1.40	1.75c	0.166
NI	5.90	5.69	6.15	5.81	0.343	5.76	4.39	5.26	5.20	0.461	6.34	7.10	6.93	7.84	0.479
CD	0.42b	1.47	2.16	3.50d	0.164	0.62b	3.37	4.86	8.79d	0.942	0.24b	3.34	5.47	10.83dF	0.220

\+ STANDARD DEVIATION
++ 70 C WEIGHT BASIS
a CONTROL VS ALL SLUDGE LEVELS (P<0.05)
b CONTROL VS ALL SLUDGE LEVELS (P<0.01)
c LINEAR EFFECT WITHIN SLUDGE LEVELS (P<0.05)
d LINEAR EFFECT WITHIN SLUDGE LEVELS (P<0.01)
e QUADRATIC EFFECT WITHIN SLUDGE LEVELS (P<0.05)
f QUADRATIC EFFECT WITHIN SLUDGE LEVELS (P<0.01)

SECTION 5

REFERENCES

Akinsoyinu, A. O., O. O. Tewe, and A. U. Mba. 1979. Concentration of trace elements in milk of West African dwarf goats as affected by state of lactation. J. Dairy Sci. 62: 921-924.

Alexander, G. V., R. E. Nusbaum, N. S. MacDonald. 1951. The boron and lithium content of human bones. J. Biol. Chem. 192: 489.

Archibald, J. G. 1958. Trace elements in milk: A review. Dairy Sci. Abst. Vol. 20, No. 9.

Bernard, A., A. Goret, J. P. Bucket, H. Roels, and R. Lauwerys. 1980. Significance of cadmium levels in blood and urine during long-term exposure of rats to cadmium. J. Tox. Environ. Health. 6: 175-184.

Bertrand, J.E., M.C. Lutrick, H.L. Breland, and R.L. West. 1980. Effects of dried digested sludge and corn grown on soil treated with liquid digested sludge on performance, carcass quality, and tissue residues in beef steers. J. Animal Sci. 50: 35-40.

Buck, W. B. and G. D. Oswieler. 1976. In Clinical and diagnostic veterinary toxicology. 2nd ed. p. 324. Kendall-Hunt, Dubuque, IA.

Chaney, R. L. 1980. Health risks associated with toxic metals in municipal sludge. pp. 59-83. In G. Britton, B. L. Damron, G. T. Edds, and J. M. Davidson (eds.). Sludge-Health risks of land application. Ann Arbor Sci. Pub., Ann Arbor, MI.

Decker, A. M., R. L. Chaney, J. P. Davidson, S. B. Mohanty, R. C. Hammond, and T. S. Rumsey. 1980. Animal performance on pastures topdressed with liquid sewage sludge and sludge compost. pp. 37-41. In Proc.Natl. Conf. on Municipal and Industrial Sludge Utilization and Disposal. Information Transfer, Inc., Silver Springs, MD.

Dorn, C. R., J. O. Pierce, II, G. R. Chase, and P. E. Phillips. 1973. Cadmium, copper, lead and zinc in blood, milk, muscle and other tissues of cattle from an area of multiple source contamination. pp. 191-203. In D. D. Hemphill (ed.). Trace substances in environmental health, VII. Univ. Missouri, Columbia, MO.

Dowdy, R. H., P. K. Morphew, and C. E. Clapp. 1981. The relationship between the concentration of cadmium in corn leaves and corn stover grown on sludge amended soils. pp. 466-477. In Proc. 4th. Annual Madison Conf. on Municipal and Industrial Waste, Sept. 28-30, Madison, WI.

Dowdy, R. H., W. E. Larson, J. M. Titrud, and J. J. Latterell. 1978. Growth and metal uptake of snap beans grown on sewage sludge-amended soil: A four-year study. J. Environ. Qual. 7:252-257.

Dowdy, R. H., W. E. Larson, and E. Epstein. 1976. Sewage sludge and effluent use in agriculture. pp. 138-153. In Proc. Land Applic. of Waste Materials Conf., Soil Conserv. Soc. Amer., Ankeny, IA.

Doyle, J. J. and W. H. Pfander. 1975. Interactions of cadmium with copper, iron, zinc, and manganese in bovine tissue. J. Nutr. 105: 599-606.

Doyle, J. J., W. H. Pfander, S. E. Grebing and J. O. Pierce, II. 1974. Effect of dietary cadmium on growth, cadmium absorption and cadmium tissue levels in growing lambs. J. Nutr. 104: 160.

Environmental Protection Agency. 1979. Criteria for classification of solid waste disposal facilties and practices. Federal Register 4: 53438-53468.

Fick, K. R., C. B. Ammerman, S. M. Miller, C. F. Simpson and P. F. H. Loggins. 1976. Effect of dietary lead on performance, tissue mineral composition and lead absorption in sheep. J. Anim. Sci. 42: 515.

Fitzergald, P. R. 1980. An evaluation of the health of livestock exposed to anaerobically digested sludge from a large community. pp. 32-36. In Proc. Nat'l. Conf. Municipal and Industrial Sludge Utilization and Disposal. Information Transfer, Inc., Silver Springs, MD.

Flick, D. F., H. F. Kraybill and J. Dimitroff. 1971. Toxic effects of cadmium: a review. Environ. Res. 4: 71-85.

Forbes, R. M., A. R. Cooper, H. H. Mitchell. 1954. On the occurrence of beryllium, boron, cobalt and mercury in human tissues. J. Biol. Chem. 209: 857.

Freeman, H. C. and J. F. Uthe. 1974. An improved hydride generation apparatus for determining arsenic and selenium by atomic absorption spectroscopy. Atom. Absorp. Newsl. 13: 75-76.

Friberg, L., M. Piscator, and G. Nordberg. 1971. pp. 27-139. In Cadmium in the environment. CRC Press, Cleveland.

Goering, H. K. and P. J. Van Soest. 1970. Forage fiber analysis (apparatus, reagents, procedures and some applications). USDA Handbook No. 379.

Gunn, S. A. and T. C. Gould. 1957. Selective accumulation of ^{115}Cd by cortex of rat kidney. Proc. Soc. Exp. Biol. Med. 96: 820.

Haenlein, G. F. W. 1980. Mineral nutrition in goats. J. Dairy Sci. 63:1729-1748.

Hamilton, E. I., M. J. Minske, and J. J. Cleary. 1972/1973. Concentration and distribution of some stable elements in healthy human tissue from the United Kingdom. Sci. Tot. Environ. 1: 341.

Heffron, C. L., J. T. Reid, D. C. Elfving, G. S. Stoewsand, W. M. Haschek, J. N. Telford, A. K. Fun, T. F. Parkinson, C. A. Bache, W. H. Gutenmann, P. C. Wszolek, and D. J. Lisk. 1980. Cadmium and zinc in growing sheep fed silage corn grown on municipal sludge amended soil. J. Agric. Food Chem. 28: 58-61.

Hennig, A., M. Anke, B. Groppel and H. Leudke. 1974. Secondary copper deficiency in ruminants. In Proc. 2nd Int. Symp. Trace Element Metabol. Animals, Madison, WI. Univ. Park Press, Baltimore, MD. p. 726.

Hinesly, T. D., R. L. Jones, E. L. Ziegler, and J. J. Tyler. 1977. Effects of annual and accumulative applications of sewage sludge on assimilation of zinc and cadmium by corn (Zea mays L.). Environ. Sci. Tech. 11: 182-188.

Hove, E. J., C. A. Elvehjem and E. B. Hart 1939. Boron in animal nutrition. Am. J. Physiol. 127: 689.

Huntington, G. B., R. A. Britton, and R. L. Prior. 1981. Feed intake, rumen fluid volume and turnover, nitrogen and mineral balance and acid-base status of whethers changed from low to high concentrate diets. J. Animal Sci. 52(6): 1376-1380.

Jordan, R. M., H. F. Hanke, H. G. Croom, and H. F. Windels. 1971. Three decades of Minnesota lamb feeding. Minnesota Agric. Exp. Stn. Bull. no. 504.

Kelling, K. A., D. R. Keeney, L. M. Walsh, and J. A. Ryan. 1977. A field study of the agricultural use of sewage sludge: III. Effects of uptake and extractability of sludge-borne metals. J. Environ. Qual. 6: 352-358.

Kienholz, E. W. 1980. Effect of toxic chemicals present in sewage sludge on animal health. pp. 153-171. In G. Britton, B. L. Damron, G. T. Edds, and J. M. Davidson (eds.). Sludge-Health risks of land application. Ann Arbor Sci. Pub., Ann Arbor, MI.

Larson, B. L. 1978. The dairy goat as a model in lactation studies. J. Dairy Sci. 61:1023-1029.

Lee, H. J. and G. B. Jones. 1976. Interactions of selenium, cadmium, and copper in sheep. Aust. J. Agric. Res. 27: 447.

Lucis, O. J., R. Lucis, and Z. A. Chaikh. 1972. Cadmium and zinc in pregnancy and lactation. Arch. Environ. Health 25:14.

Margoshes, M., and B. L. Vallee. 1957. A cadmium protein from equine kidney cortex. J. Am. Chem. Soc. 79: 4813.

Marten, G. C., W. E. Larson, and C. E. Clapp. 1980. Effects of municipal waste-water effluent on performance and feed quality of maize vs. reed canarygrass. J. Environ. Qual. 9: 137-141.

Marten, G. C. and R. F. Barnes. 1979. Prediction of energy digestibility of forages with in vitro rumen fermentation and fungal enzyme systems. pp. 61-71. In Proc. Int. Workshop of Standardization of Analytical Methodology of Feeds, March 12-14, 1979. Int. Dev. Res. Center and Int. Union Nutrit. Sci., IDRC-134e, Ottawa, Ontario.

Marten, G. C., R. D. Goodrich, A. R. Schmid, J. C. Meiske, R. M. Jordan, and J. G. Linn. 1975. Evaluation of laboratory methods for determining quality of corn and sorghum silages: II. Chemical methods for predicting in vivo digestibility. Agron. J. 67: 247-251.

Meek, E. A. 1959. Cellular changes induced by cadmium in mouse testis and liver. Brit. J. Exp. Path. 40: 503.

Melton, J. R., W. L. Hooper, and P. A. Howard. 1971. Determination of mercury in soils by flameless atomic absorption. Soil Sci. Soc. Am. Proc. 35:850-852.

Merck Vet. Manual. 1973. O. H. Siegmund, ed. Merck & Co., Inc., Rathway, NJ.

Miller, W. J. 1971. Cadmium absorption, tissue and product distribution, toxicity effects and influence on metabolism of certain essential elements. p. 58 in Proc. GA Nutr. Conf.

Miller, W. J., D. M. Blackmon, R. P. Gentry and F. M. Pate. 1969. Effect of dietary cadmium on tissue distribution of ^{109}Cd following a single dose in young goats. J. Diary Sci. 52: 2029.

Miller, W. J., B. Lampp, G. W. Powell, C. A. Salotti, and D. M. Blackmon. 1967. Influence of a high level of dietary cadmium on cadmium content of milk, excretion and cow performance. J. Dairy Sci. 50:1404-1408.

Mills, C. F., and A. C. Dalgarno. 1972. Copper and zinc status of ewes and lambs receiving increased dietary concentrations of cadmium. Nature 239: 171-173.

Murthy, G. K. and U. Rhea. 1968. Cadmium and silver content of market milk. J. Dairy Sci. 51:610-613.

National Research Council. 1980. Mineral tolerance of domestic animals. Nat'l. Acad. Sci., Washington, D.C., 577 pp.

Neathery, M. W. and W. J. Miller. 1975. Metabolism in animals of cadmium, mercury and lead as related to their toxocology and ecology. Proc. GA Nutr. Conf. p. 65.

Neathery, M. W., W. J. Miller, R. P. Gentry, P. E. Stabe, and D. M. Blackmon. 1974. Cadmium - 109 and methyl mercury - 203 metabolism, tissue distribution, and secretion into milk of cows. J. Dairy Sci. 57:1177-1183.

O'Dell, G. D., W. J. Miller, S. L. Moore, W. A. King, J. C. Ellers, H. Jurecek. 1971. Effect of dietary nickel level on excretion and nickel content of tissues in male calves. J. Anim. Sci. 32: 769.

Parkash, S. and R. Jenness. 1968. The composition and characteristics of goat's milk: A review. Dairy Sci. Abstr. 30(2):67.

Perry, H. M., Jr. and M. W. Erlanger. 1974. Hypertension following the chronic feeding of low doses of cadmium and mercury. Fed. Proc. Fed. Am. Soc. Exp. Biol. 33: 357.

Perry, H. M., Jr., and A. Yuncie. 1965. Acute pressor effects of intraarterial cadmium and mercuric ions in anesthetized rats. Proc. Soc. Exp. Biol. Med. 120: 805.

Pinkerton, C., D. I. Hammer, K. Bridbord, J. P. Creason, J. L. Kent, and G. K. Murthy. 1973. Human milk as a dietary source of cadmium and lead. pp. 39-43. In D. D. Hemphill (ed.). Trace substances in environmental health - VI. Univ. of Missouri Pub., Columbia.

Powell, G. W., W. J. Miller, J. D. Morton and C. M. Clifton. 1964. Influence of dietary cadmium level and supplemental zinc or cadmium toxicity in the bovine. J. Nutr. 84: 205.

Ryan, J. A., H. R. Pahren, and J. B. Lucas. 1982. Controlling cadmium in the human food chain: A review and rationale based on health effects. Environ. Research 28: 251-302.

Schroeder, H. A. and A. P. Nason. 1974. Interactions of trace metals in rat tissues. Cadmium and nickel with zinc, chromium, copper, manganese. J. Nutr. 104: 167-178.

Schroeder, H. A., J. J. Balassa and W. H. Vinton, Jr. 1964. Chromium, lead, cadmium, nickel and titanium in mice: Effect on mortality, tumors and tissue levels. J. Nutr. 83: 239.

Schroeder, H. A., W. H. Vinton, Jr., and J. J. Balassa. 1963. Effects of chromium, cadmium, and other trace metals on growth and survival of mice. J. Nutr. 80:39-47.

Schroeder, H. A., J. J. Balassa, I. H. Tipton. 1961. Abnormal trace metals in man:Cadmium. J. Chron. Dis. 14: 236.

Sharma, R. P., J. C. Street, M. P. Verma, and J. L. Shupe. 1979. Cadmium uptake from feed and its distribution of food products of livestock. Environ. Health Perspect. 28:59-66.

Simpson, G. G. 1945. Principles of classification and a classification of mammals. Bulletin Am. Museum of Nat. History 85.

Smith, D. H., G. C. Marten, and R. A. Britton. 1982. Takadiastase enzyme pretreatment for determining cell wall constituents in corn and sorghum silages. Agron J. 74: 77-80.

Sommers, L. E. 1977. Chemical composition of sewage sludges an analyses of their potential use as fertilizers. J. Environ. Qual. 6: 225-232.

Speed, F. M., R. R. Hocking, and O. P. Hackney. 1978. Methods of analysis of linear models with unbalanced data. J. Am. Stat. Assoc. 73(361): 105-112.

Stabel-Taucher, R., E. Nurmi, and E. Kuppanen. 1975. Content of copper, zinc, lead, cadmium, and mercury in muscle, liver, and kidney of Finnish cattle. J. Sci. Agric. Soc. Finland. 47: 469.

Standish, J. F., C. B. Ammerman. 1971. Effect of excess dietary iron as ferrous sulfate and ferric citrate on tissue mineral composition of sheep. J. Anim. Sci. 33: 171.

Standish, J. F., C. B. Ammerman, A. Z. Palmer and C. F. Simpson. 1971. Influence of dietary iron and phosphorus on the performance, tissue composition and mineral absorption in steers. J. Anim. Sci. 33: 171.

Sunderman, F. W., Jr., M. J. Decsy, and M. D. McNeely. 1972. Nickel metabolism in health and disease. Ann. NY Acad. Sci. 199:300.

Task Group on Metal Accumulation. 1973. Accumulation of toxic metals with specific reference to their absorption, excretion and biological half-times. Environ. Physiol. Biochem. 3: 65.

Underwood, E. J. 1977. Trace elements in human and animal nutrition. Fourth Ed. Academic Press, NY.

Underwood, E. J. 1971. Trace elements in human and animal nutrition. 3rd. Ed., Acad. Press, New York.

Watson, L. T., C. B. Ammerman, J. P. Fester and C. E. Roessler. 1973. Influence of manganese intake on metabolism of manganese and other minerals in sheep. J. Anim. Sci. 36: 131.

Whanger, P. D. 1973. Effects of dietary nickel on enzyme activities and mineral content in rats. Toxicol. Appl. Pharmacol. 25: 323.

World Health Organization. (W.H.O.) 1972. Expert committee on trace elements in human nutrition. Tech. Rep. Serv. 532.

Wright, F. C., J. S. Palmer, J. C. Riner, M. Haufler, J. A. Miller and C. A. McBeth. 1977. Effects of dietary feeding of organocadmium to cattle and sheep. J. Agric. Food Chem. 25: 293.